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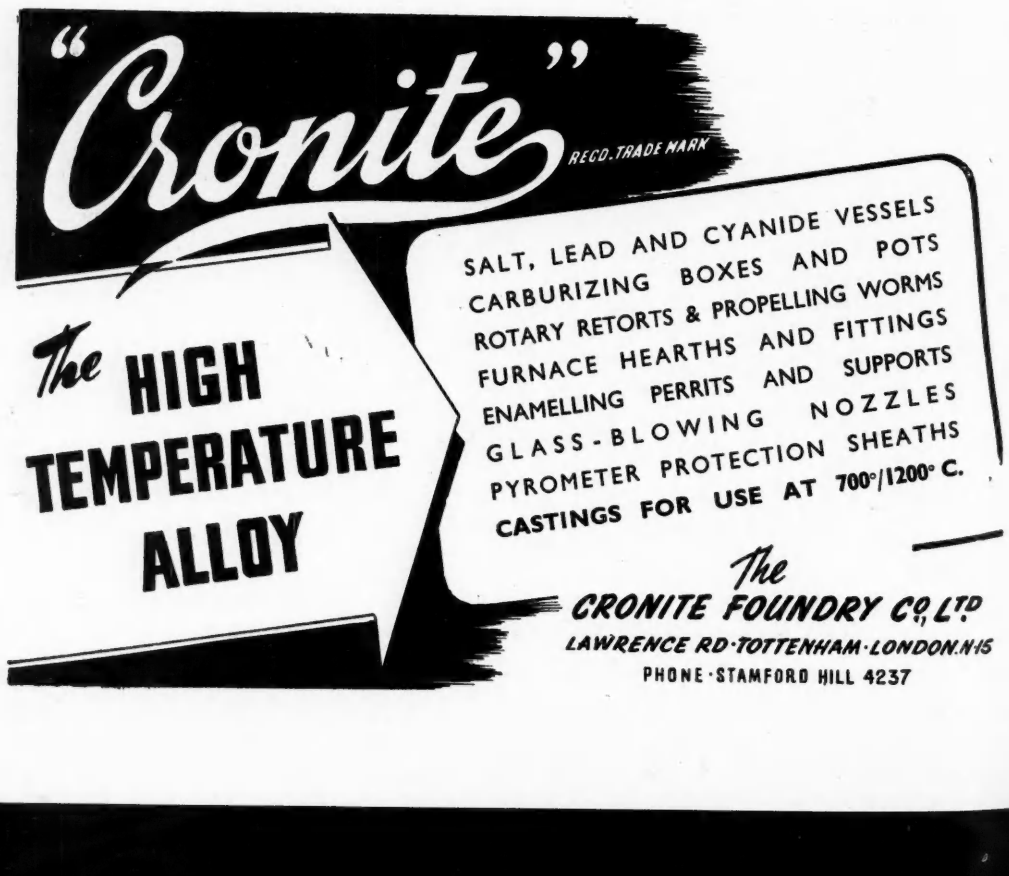


The Manufacture of Photo-Electric Cells

By J. BERTHILLIER. (From *Électricité*, Vol. 31, No. 126, April, 1947, pp. 69-74, 13 illustrations.)

THE photo-electric cells considered in this article are of the photo-emissive type and should be clearly distinguished from photo-voltaic or photo-conductive cells which are not directly based on the electron principle. Since the first experiments by Becquerel, photo-emissive cells have been considerably improved, both as regards sensitivity and current output.

Overall sensitivity has been increased by using cesium instead of the alkali or alkaline earth metal layers originally employed (in the earliest types of cells, hydrided magnesium, obtained by passing a glow discharge through hydrogen gas, and later hydrided sodium or potassium were used). Spectral sensitivity has been improved by endeavouring to obtain maximum response to the light sources most generally used for excitation, i.e., tungsten filament lamps with a radiation rich in red and infra-red rays, and ordinary daylight, with a greater blue radiation component. Two types of cathodes have been specially developed for these two sources, viz. : the cesium-oxide and the antimony cathodes, and their production will be described in this article. The spectral sensitivity curves of these two cells are

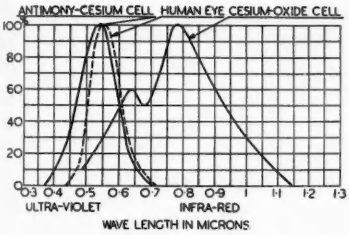


Fig. 1.

shown in Fig. 1, the current output being indicated not as an absolute value but as a percentage relative to the corresponding wavelength of the incident light.

CESIUM OXIDE CATHODES.

The cesium-oxide layers are generally much more complex than the formula ($AgCs_2O$) by which they are characterized. Experiments with cesium metal deposited on a silver plate and then subjected to gradual oxidation did not give successful results. It was thus necessary to use a substratum of silver oxide to support the superficial film of cesium, the various layers diffusing into each other at a molecular scale so as to form a complex surface (Fig. 2). Cesium oxidizes immediately in the presence of air and therefore cesium metal films can only be examined in vacuum or in an inert gas such as argon. The general method for preparing these layers is to get metallic cesium to react at a determined temperature with a layer of silver oxide previously prepared.

The cathode is of silver or of electrolytic copper covered with an electrolytic deposit of silver. The materials employed must be very nearly pure, even more than in the case of wireless valves, as the slightest traces of certain elements can reduce the photo-electric properties or be the cause of defective functioning. The cathode is generally designed as a cylindrical plate in order to have a potential gradient as homogeneous as possible over the entire cathode surface. The anode is a straight rod usually of nickel, situated at the centre of the cylinder, all the photo-electrons thus being subjected to the same attractive force.

Each of the two electrodes is connected through a vacuum-seal passage to two external conductors which are subsequently fixed on to the socket. The base contains, as usual in all bulbs, a press, i.e., a small tube used for pumping (see Fig. 3). The glass used for the bulb must be free from lead salts, but the base is generally of lead glass, for reasons which will be explained later. To maintain intimate contact these two types of glass must have nearly the same thermal expansion coefficients over a fairly large temperature range.

Pumping. The cells are first evacuated in the same way as ordinary light bulbs, that is, a good vacuum of about 10^{-5} mm mercury must be reached, the bulb then being baked at about 400 deg. C. to eliminate residual gases and the water vapour adhering to the walls.

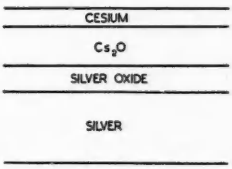


Fig. 2.

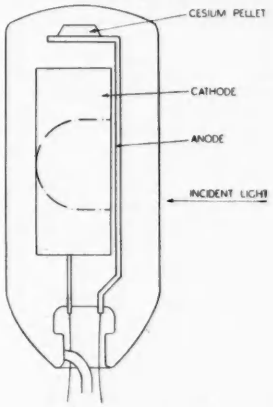


Fig. 3.

Induction heating of the cathode metal is not possible because of the tendency of silver to evaporate at 600 deg. C. which would then result in a colouring of the walls and an absorption of light. Therefore a particularly thorough outgassing before assembly is required.

Oxidation. After baking and cooling, extremely pure oxygen at a pressure of about 1 mm is admitted into the cell. This is achieved, for instance, by decomposition of purified potassium permanganate as a result of a slight heating, according to the equation :

$$10\,KMnO_4 \rightarrow 2\,K_2MnO_3 + (3\,K_2MnO_4 + 5\,MnO_2) + 6\,O_2$$

A superficial oxidation of the silver is obtained, for instance, by means of a current discharge (preferably d.c.) between the cathode and the anode, using a potential of about 500-600 volts, with an output of a few milliamperes. The extent of the oxidation can be regulated either by varying the oxygen pressure, i.e. calculating the fixed quantity of oxygen for a given weight of silver, particularly in the case of very thin films on glass (semi-transparent cathodes), or more generally by observing the colour acquired by the silver. The oxide layer determines by interference with light a series of characteristic colours which depend on the film thickness and not on the condition of the surface, the cycle of colours being, in the order of increasing oxide thicknesses : yellow, orange, violet, blue, green, yellow, red, green, etc. The blue colour corresponding to a thickness of about 800 molecules of oxide is generally chosen as giving the best results.

Preparation of cesium. The cesium which has to be made to react with the silver oxide is extremely oxidizable, and should therefore be prepared only just

before using, either in the cell itself, or in an adjacent container, under vacuum. Various reactions can be employed, such as the reduction of a cesium salt (chloride, dichromate, chromate, etc.) by a reducing metal (zirconium, silicium, aluminium, etc.) ; and one of the most generally used reactions is

$$2\ CrO_4Cs_2 + 2{\cdot}5\ Zr \rightarrow Cr_2O_3 + 4\ Cs + 2{\cdot}5\ ZrO_2.$$

The reaction occurs at a temperature of 700-800 deg. C. To obtain this reaction, a pellet consisting of a compressed pulverized mixture of cesium salts and reducing metal (with an excess quantity of the latter, to facilitate a complete reaction) is enclosed in a metal cup, which is then heated by means of eddy currents induced by a high-frequency generator. The cesium thus liberated deposits on the walls of the ampoule containing the cup in the form of a slightly yellowish metal which is liquid at temperatures above 28 deg. C. and which can, therefore, be ejected by a slight heating of the wall by contact with a hot surface.

Activation. Three processes can be applied for the final preparation of the layer. The first consists in producing just the quantity of cesium required to obtain a suitable layer. This quantity can be calculated roughly for a given amount of silver oxide and then be more accurately determined after a few tests. In this case the cesium is prepared in the cell itself and the cup is placed as indicated in Fig. 3. The entire cell is then heated to about 200 deg. C. The cesium is ejected from the cup and deposits on the cathode which has remained comparatively cold. When the cathode reaches a temperature of 180-190 deg. C. the reduction of the silver oxide by the cesium will take place.

In spite of its simplicity, this method is not frequently used, as the optimum composition of the sensitive layer must be very accurately determined, a slight excess or lack of cesium leading to a much lower sensitivity. As there are two slightly variable constants in this process (the quantity of oxide which depends on a determination of colour or of pressure, and the amount of cesium which can vary within certain limits, according as the reaction is more or less complete), a certain amount of error is involved. For instance, the reaction depends on the size of the grains of powder and the homogeneity of the mixture. Furthermore, a third factor which can have a considerable effect is the absorption of cesium by other parts such as the anode, the glass, etc., or, on the contrary, the liberation of oxygen fixed by these surfaces during the oxidation.

The second process, developed from the first, consists in preparing slightly more cesium than theoretically necessary and having it absorbed in excess of the required amount. The glass base of the bulb can also have a part in this process. When cesium is heated in the presence of lead glass, it will reduce the lead oxide of the glass, so that lead metal will be liberated, this being evidenced by a blackening of this glass. The excess cesium can thus be eliminated by the lead glass in the press or base, but lead glass should not be used in the bulb, to avoid producing an opaque surface. A similar reaction can also be obtained with an easily reducible oxide (copper or lead oxides) deposited at any convenient position in the cell.

The cesium can be ejected on to the cathode in the same way as in the first activation process. The cell is gradually heated while the base is subjected to an adjustable amount of additional heating, so that a certain equilibrium is obtained between the reaction on the cathode and the absorption of the excess cesium by the base. This process requires considerable skill and a good knowledge of the variation of colours of the layers, and is not therefore suitable for industrial work.

The third process is the easiest to apply : the cesium is produced in an adjacent container and introduced gradually into the cell through a calibrated capillary tube. In this manner just the right quantity is admitted, and the cesium reservoir is then cooled so that it will retain the excess metal. A lead glass base can also be used to absorb the excess cesium, and a particularly good arrangement is to introduce the cesium through the lead glass press. Although some of the cesium is absorbed while passing through it, the reaction is sufficiently slow to let a certain amount pass through to the cathode. As the reaction with the lead oxide only begins at 140 deg. C. and becomes more and more rapid with increasing temperatures, this method enables a nearly automatic regulation of the amount of cesium to be achieved.

Regulation of the activation. The problem is to determine the moment at which the cathode reaches its maximum sensitivity. The first suggestion would be to reproduce operating conditions, that is, to illuminate the cathode with a constant light source, and to apply a d.c. voltage between the cathode and the anode, and follow the rise of the current flowing through the circuit. There is, however, a disturbing factor : the thermionic emission of the cesium oxide is much greater than the photo-electric emission at the reaction temperature of 180-200 deg. C., and as, furthermore, the thermionic current varies considerably with temperature, its fluctuations are of the same order of magnitude as the photo-electric current.

There are, however, two accurate methods of determining the activation of the cathode. The first is to measure the thermionic current in order to find its maximum, as in the case of normal layers this also corresponds to maximum sensitivity.

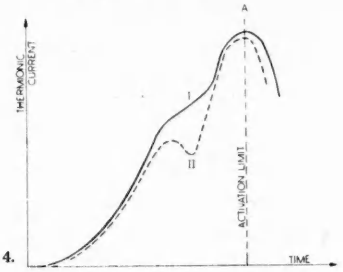


Fig 4.

Consider for instance a cell for which the cesium has been prepared in an adjacent appendage. The two units are heated in an oven up to a given temperature between 180 and 200 deg. C. (the temperature variation not exceeding $\pm$ 2 deg.). The two electrodes of the cell are connected to a d.c. supply and a microammeter is included in the circuit. The variation of current against time will then be observed to follow a course such as that of curve I in Fig. 4. As soon as the maximum current is reached (point of inflexion A) the cell and its appendage are both rapidly removed from the oven. The thermionic current will then drop rapidly, while at the same time the photo-electric current (which can be measured by another method still to be described) will rise considerably because of the external illumination if the point thus determined is the actual maximum of the current. It should be noted that sometimes curves such as curve II have been recorded, with a secondary maximum corresponding to an unstable condition of the layer. If the cell is removed at this moment, the thermionic current will drop rapidly but no photo-electric current will be registered.

Conditions may vary slightly according to the structure of the cell. For instance, in a cell with a massive cathode within the bulb, part of the free cesium may condense on the walls which cool more rapidly after the cell has been taken out of the oven. In such a

case, one should go well beyond the maximum of the thermionic current. In the opposite case, where the cathode is a silvered deposit on the glass, the maximum should be accurately maintained. Only considerable experience enables to determine the optimum working conditions.

The second method of regulating activation is to have the cell illuminated by a discontinuous flux such as is obtained with light passing through a rotating perforated disk. In this way the thermionic and the photoelectric current will correspond to a continuous and a periodically variable current, respectively. The periodic pulses can then be observed on an oscillograph with a time-sweep synchronized to the resultant frequency. The holes of the disk can also be covered with filters only letting through limited bands of the light spectrum, so that it will be possible to follow not only the overall activation but also the variation in spectral sensitivity. The sensitivity during activation has been found to shift towards the greater wavelengths, i.e., towards the infra-red region.

Various secondary phenomena affect the apparent simplicity of this method. For instance, the nearer one comes to the optimum layer thickness, the greater will be the tendency to have free cesium in the bulb since there is no more silver oxide left to fix it. This cesium is ionized by the potential applied to the cell, even if this is a very low potential, and the ions then tend to create a current opposite in direction to the electronic current being observed, so that it can occur that the current pulses registered on the oscillograph may have negative amplitudes.

A third method of determining the activation, which, although not as accurate, can be used for industrial production, is to observe the changes in colour of the cathode, which vary with the phase of the reaction. This method requires considerable experience to be applied successfully but gives good results. All these processes and their regulation have to be applied with great accuracy to each photocell separately, and do not lend themselves to mass production, so that the manufacturing costs are necessarily high. An error of $\pm$ 10 deg. in the activation temperature, or of $\pm$ 10 per cent in the amount of cesium, will lead to cathodes of much lower efficiency.

In the case of the cesium prepared in an adjacent container, when the reaction has developed to its optimum point, the container appendage is separated from the cell proper by melting the glass connecting tube. A certain amount of cesium is liberated during this operation which is absorbed by the connecting tube and by the oxygen coming from the flame which diffuses through the molten glass. Sensitivity is generally considerably affected by this operation but it can be raised again by a re-heating of the cell at about 150 deg. C., which also fixes the cesium which may have remained free and which on account of defective insulation could be the cause of sputtering or of considerable dark currents.

Superactivation. Various attempts have been made to improve the cathodes previously described, but it seems difficult to exceed a response of 50 microamperes per lumen with a normal incandescent lamp at 2,700 deg. K.

The superactivation method applied is as follows : After the optimum film thickness has been obtained by the processes already described, a small amount of silver is evaporated. This causes generally a slight decrease in sensitivity, but if in this condition the cell is subjected to heating at about 180 deg. C., the silver will diffuse into the layer and the overall sensitivity will be higher than the initial value. At the same time the spectral sensitivity will shift again towards the infra-red region, with a threshold of sensitivity at about 14,000 Angström. In this manner responses as high as 100 microamperes per lumen have been obtained. However, superactivation is a delicate operation, and is only used for certain special types of cells. Furthermore, it also requires the presence of a silver evaporator, and hence of an additional terminal for the current, as well as a mask to avoid tarnishing the surface through which the light enters, and all these elements are obstacles to the incident light.

VACUUM CELLS AND GAS-FILLED CELLS.

The cathodes described above are used in vacuum cells and in gas-filled cells. The vacuum cells have a high degree of vacuum, of the order of the vapour-pressure of cesium. The gas-filled cells are at a comparatively high pressure of about 0·10 mm Hg. Generally argon is used ; the argon must be extremely pure and free from moisture, and it is introduced into the cell before it is separated from the pumping assembly.

It should be noted that if the cesium is admitted from an adjacent container, the gas will exist both in the cell and in the appendage, and the argon pressure, although low, will be important relative to the pressure of the cesium vapour during the activation, so that the rate of diffusion of the vapour will be decreased. This factor should be remembered in determining the constants of the capillary supply tube.

The effect of the filler gas is to increase the apparent sensitivity of the cell. The electrons leaving the cathode collide with the gas molecules, but as long as the applied voltage is low the shocks are elastic and there is practically very little difference between the functioning of the cell and that of a vacuum valve. Beyond a certain voltage (about 15-20 volts for argon), known as the ionization voltage, the electrons have sufficient energy to ionize the gas, and the current output increases then in proportion to the applied voltage. The response curve as a function of voltage for a constant illumination is shown in Fig. 5 for the vacuum and the gas-filled cell.

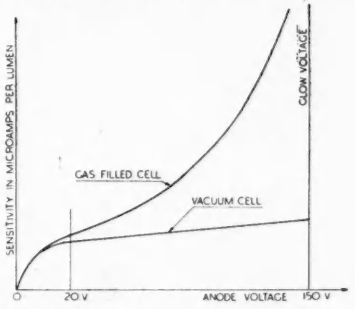


Fig. 5.

The dark current or background noise of a gas-filled cell is due to gas ionization, in the absence of light, by electrons produced as a result of thermionic emission at the ambient temperature. With increasing voltages for a given illumination the ionization increases, and at a certain voltage, known as the glow voltage, it becomes a self-maintaining glow discharge, corresponding to the asymtotic part of the curve in Fig. 5, for which the current is practically limited only by the resistance of the external circuit. The cell then operates as a gas valve ; but the emissive layer of the cathode deteriorates very rapidly, so that the number of electrons leaving the cathode is reduced and the ionization drops down to a more normal value. To avoid detrimental effects it is, therefore, advisable to operate the cell at a value below this critical 20-30 volts and to insert in the circuit a protective resistance limiting the output. Under such conditions the gaseous amplification factor is usually between 5 and 8. In all cases, both in vacuum and in gas-filled cells, the output of a cesium-oxide type cathode should be maintained below approximately 1 microampere per square centimetre of surface, to avoid destruction of the cathode.

ANTIMONY-CESIUM CATHODES.

These cathodes have a response curve which is displaced relative to that of the cesium-oxide type cells, and the processes for their preparation are also different. The layers are merely an alloy of antimony and cesium, which need not be prepared in exact proportions, but the activation temperature is a function of the relative quantities of cesium and antimony used.

The antimony is generally deposited as a very thin layer by evaporation under vacuum at about 300 deg. C., and various methods can be employed.

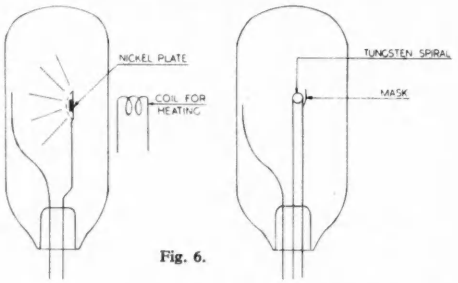


Fig. 6.

The piece of antimony metal can for instance be placed on a nickel plate on the top of the anode and held in place by a thin wire meshing (Fig. 6). On heating with induced currents the metal molecules are projected towards the rear, while the front surface of the bulb is kept free for the incident light. A wire contacting with the glass cathode is then connected to the cathode terminal. Certain authors point out that cathodes prepared in this way do not give optimum response, the evaporated metal containing a certain proportion of nickel. Furthermore, the plate holding the antimony must be large enough to enable it to be heated without using an extremely powerful generator, but a plate of this size is then an obstruction to light and reduces the useful area. For these reasons a tungsten spiral covered with an electrolytic deposit of antimony is sometimes used instead of the previous arrangement.

Once this layer has been obtained, the cesium vapour can either be made to react at a fixed temperature according to determined proportions, or cesium can be introduced even without heating, the temperature of the assembly being then raised to a value depending on the amount of cesium employed.

A characteristic feature of these processes is the more or less total absence of thermionic currents, probably because no oxygen is available to react with the cesium. The activation can thus be followed by simple photo-electric measurement. For the case of a gradual admission of cesium at constant temperature, the sensitivity curve as a function of time is shown in Fig. 7. The first plateau which may sometimes even have a slight depression seems to correspond with a first alloy formation which is relatively stable but with a sensitivity well below that of the real maximum.

The arrangements for the admission of cesium do not differ for these cathodes from those employed for cesium-oxide cathodes which have already been described. However, because of the type of alloy used, their preparation is much easier. Whereas in the case of silver-oxide base-layers an excess of cesium results in a definite loss of sensitivity, due apparently to a complete reduction of the intermediate layer of silver oxide which cannot be reversed, with antimony-cesium cells, if there is an excess of cesium and a corresponding lack of sensitivity relative to the optimum value, this can be eliminated by absorption according to the methods already described.

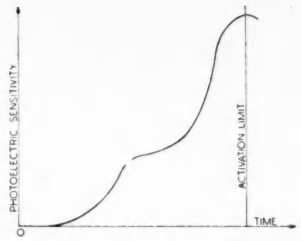


Fig. 7.

Response. Few articles have been published on the superactivation of these cells. Under normal conditions a mean sensitivity of 15-20 microamperes per lumen can be expected with an incandescent lamp light at 2,700 deg. K., which is a much lower value than that for the cesium-oxide cathodes ; but the sensitivity peak is in the blue region, which means that with another source such as daylight this sensitivity will be much higher. Therefore, for the electronic equipment using such radiations (for instance, scanning equipment, daylight regulated cells, etc.) these layers will be far superior to the $AgCs_2O$ type layers. It does not seem that these cells have been produced with a gas filling, and this may restrict their possibilities. A great advantage is the excellent electrical conductivity of very thin layers, which are therefore very transparent to light, whereas this is not the case with cells with a silver substratum.

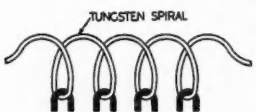


Fig. 8.

Silver has good evaporating properties. Evaporation can be achieved for instance by fitting little silver loops on to a tungsten wire which is then heated up to 1,200-1,500 deg. C. (Fig. 8). Extremely thin layers can thus be obtained on the cathode and their thickness can be determined from their opacity to light. But a limit to the fineness of the layers is given by the so-called mosaic phenomenon. When heated in the presence of air or under vacuum the layer changes gradually into a discontinuous structure, under the influence of surface tension, and at higher temperatures the silver forms into minute spheres varying from 1 to 20 microns in size which adhere firmly to the supporting surface. The discontinuous surface has a very high resistivity and the potential of the different parts of the cathode is not sufficiently determined, since the grains emitting negative electrons then acquire positive potentials. This phenomenon also tends to occur during oxidation in the pre-treatment of the cathode or when the silver film is in contact with air after evaporation. Antimony does not have this drawback, and can therefore be used to make thin films with a transparency as high as 80 per cent. Antimony-cesium cathodes give greater current outputs than the cesium-oxide cathodes without fatigue, and the saturation limit is less definite in antimony-cesium cells (see Fig. 9).

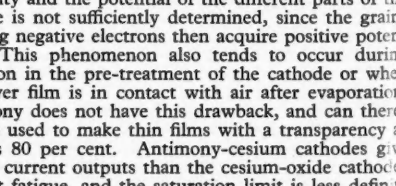


Fig. 9.

The Rebuilding of Electrical Machines

By P. Boros. (From *Elektrotechnika*, Vol. 39, No. 6, June, 1947, pp. 105-110, 1 illustration.)

1. D.C. MOTORS.

The induced e.m.f. in d.c. armatures is given by

$$E = c_1 \cdot n \cdot h \cdot \frac{z}{a} \cdot \Phi \quad .. \quad .. \quad (1)$$

where c_1 is a constant containing the number of poles of the motor, Φ the magnetic flux of a single pole, n the speed in r.p.m., h the number of slots, z the number of effective conductors per slot, and a the number of parallel circuits in the armature. Unless there is only one effective conductor in a slot, z can only be an even number, so that

$$z = \frac{c_2 \cdot k}{h} \quad .. \quad .. \quad (2)$$

where c_2 is an integer and k is the number of commutator segments. The two equations indicate what alterations are possible. c and h are fixed, k cannot be changed without making a new commutator, and ϕ is variable only within narrow limits.

Example :—Let us consider a 220 volt motor, 800 r.p.m., 4 poles, $h = 33$, $z = 6$, $k = 99$ and $a = 2$. According to the manufacturer's specification this motor can also be made to work at 600 r.p.m. According to eqn. (1), the conversion could be effected by making $z = 8$, but this conflicts with the requirements of eqn. (2). If we were to change the serial winding denoted by $a = 2$ to parallel ($a = 4$), we would have $z = 16$, which still does not satisfy eqn. (2). The value of z is thus raised to 18, decreasing Φ in the ratio 16/18. If a winding with the cross-section required for this solution can be accommodated, the armature would be suitable as regards temperature rise. But generally in such cases the required cross-section does not fit into the slots, since the insulation of conductors takes up relatively more space as the number of conductors per slot increases. In the given example the problem can be solved by using 8 conductors and 131 segments. (It is also possible to use 8 conductors and 99 segments if we ignore eqn. (2), but this leads to a very awkward method of winding.) Parallel winding, it must be noted, does not give a consistently satisfactory performance without equalizing connections, and with an odd number of segments in a 4-pole motor these connexions can only be accommodated if there is a space between the laminations and the shaft, through which the connexions can be passed from the commutator side of the armature to the other without being exposed to the effect of the magnetic field.

With motors having both main and auxiliary poles the coils of the stator must also be altered, if the winding and the current are altered in the armature ; sparking is often due to auxiliary poles of the motor having been neglected.

The conversion of ordinary d.c. motors into welding and galvanizing dynamos requires careful consideration. Modern welding dynamos are specially built to satisfy specified requirements as for instance the immediate return to the no-load voltage on cessation of the arc. An ordinary d.c. motor can be converted into a welding dynamo by using a Kraemer circuit, but this still needs a separate generator and even then it cannot compete with a modern welding machine. When conversion into a galvanizing dynamo is under consideration the first question is whether there is space for a commutator of the required size, and then, from equations (1) and (2), the number of conductors per slot must be decided upon. If the number of conductors per slot arrived at is one, a special method of winding can be used in which there is no upper and lower coil side in each slot, but only one single conductor. In this case the number of segments is half that of the number of slots, so that it is only possible in the case of a rotor with an even number of slots. If calculation leads to less than one conductor per slot and if the number of parallel circuits in the armature cannot be increased, then either n or ϕ must be decreased. But in self-excited generators the latter expedient leads to unstableness, so that in this case external excitation is necessary ; the sparking likely to occur with weak fields can be avoided by the use of auxiliary poles, which can be built in even if no provision for such poles was originally made in the motor.

In addition to these considerations it is necessary to examine whether, if n is increased, the peripheral speed is not excessive, in which case the fixing of coils and especially end connexions requires special attention. The commutation also needs controlling and the following points should be investigated : Does not the potential between the segments exceed the permissible maximum ; and is there any danger of sparking at the brushes—possibly because of an increase of the intensity of the current for which the commutator surface may be inadequate, or for which a different type of brush is required ?

II. A.C. MOTORS.

The induced e.m.f. of an a.c. motor is given by

$$E = c_3 \cdot f \cdot \Phi \cdot \nu \cdot h \cdot \frac{z}{a} \quad .. \quad (3)$$

where c_3 is a constant, ν the frequency, f the winding factor and the other symbols as in eqn. (1). In the case of 3-phase a.c. motors each winding can be used for two voltages according to whether the phases are Star– or Delta–connected. Care must be taken in taking advantage of the possibility of altering the voltage by changing the number of parallel circuits offered by eqn. (3) ; for instance, a 380 volt motor can be converted for use on 190 volts by connecting the coils originally connected in series into two parallel groups in each phase. The first condition of this is that there must be an even number of coils per phase, e.g., it is impossible with a 6-pole motor having 3 coils per phase. Experience shows that conversion is possible without ill-effects when the resistance and impedance of the coils connected in parallel is about equal. The so-called " put-in " coils always satisfy this requirement, whereas in a 4-pole winding where the end connections are arranged in two planes, it would be necessary to connect an outer (longer) and inner (shorter) coil in parallel. This would cause uneven running which cannot be eliminated even by careful compensation. If in the same motor the connexions are in three planes, there is no obstacle to parallel winding.

From eqn. (3) it also follows that a motor with a given winding may be used for various voltages ; the values of Φ vary correspondingly. This, however, is not a very fruitful possibility, since variation is confined within narrow limits ; it is inadvisable to change Φ considerably if drastic reduction of efficiency is to be avoided.

Φ can be expressed as follows :

$$\Phi = c_4 \cdot B \cdot t \quad .. \quad .. \quad (4)$$

where c_4 is a constant containing also the length of the lamination, B is the field strength in the airgap, t is the circumference of the rotor divided by the number of poles.

The torque of the motor is given by

$$M = c_5 \cdot m \cdot I \cdot w \cdot 2p \cdot \Phi \quad .. \quad (5)$$

where c_5 is a constant, m the number of phases of the rotor, I the current per phase, w the number of turns per phase, $2p$ the number of poles.

The capacity of the motor is given by

$$N = c_6 \cdot M \cdot n \cdot \quad .. \quad .. \quad (6)$$

where c_6 is a constant, and n is speed in r.p.m.

These equations enable us to answer the question as to what happens if we change the value of $2p$. If we keep B constant, then, from eqn. (4), Φ is directly proportional to t, and hence inversely proportional to $2p$. From eqn. (5), the product $p\Phi$ is constant, i.e., the torque produced by the motor is constant. Hence N varies directly with n, as shown by eqn. (6). n is given by

$$n = \frac{120 \cdot \nu}{2p} \quad .. \quad .. \quad (7)$$

This gives the synchronous speed from which the slip is to be deducted to obtain the on-load speed of the motor.

Thus the capacity varies inversely with the pole number, if B is kept constant. To find whether this is possible it is necessary to consider the magnetizing current of the motor. Fig. 1 indicates that the magnetic

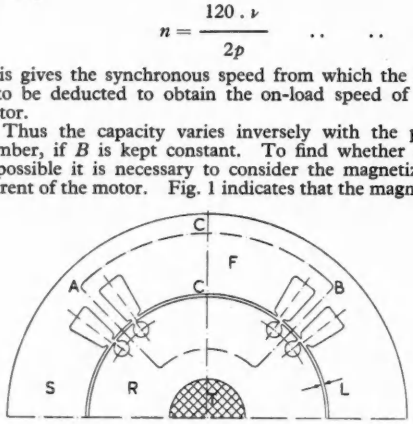


Fig. 1. Magnetic circuit of a.c. motor.
T = shaft, S = stator, R = rotor, L = airgap, F = line of force, AB = Pole arc for 4 poles, AC = Pole arc for 8 poles.

flux in a motor is a function of the length of the magnetic circuit (airgap + stator-core + stator-rim + stator-core + airgap + rotor-core + rotor-rim + rotor-core). If Φ and the dimensions of the motor are known, we can calculate the induction for each part and the number of ampere-turns required to effect it. The sum of these gives the total number of ampere-turns necessary in the motor, from which the magnetizing current can be calculated as follows :

$$I = \frac{c_7 \cdot p \cdot A}{m \cdot w \cdot f} \quad .. \quad .. \quad (8)$$

where c_7 is a constant, m is the number of phases of the stator, w is the number of turns per phase, f is the winding factor for the stator, and A is the total number of ampere-turns.

If, for instance, it is desired to rewind a 4-pole motor for 8 poles, keeping the value of B constant, then, the pole arc being half of its original value, eqn. (4) shows that Φ will also be half its original value. Hence, from eqn. (3) the number of effective conductors per slot would have to be doubled. As a result the cross-section of the conductors will have to be reduced by 50 per cent, but generally the space factor of the slot deteriorates with increasing number of conductors. If B is constant, the induction of the core also remains constant, but the induction of the ring and the length of the lines of force both fall to half their original value, corresponding to the smaller pole-number. As a result, the number of ampere-turns corresponding to the rim are also halved. However, since most of the magnetizing current in a motor is generally taken up by the airgap and the cores, the total number of ampere-turns will thereby be affected very little. And since, from eqn. (8), p and w are doubled, the magnetizing current does not change even if the conductors' cross-section is halved. In small motors, where the magnetizing current reaches 40 or even 50 per cent of the rated on-load current, such rewinding produces a motor which is heated up too much even by the no-load current, and from which very little or no useful output can be obtained. The position is made more difficult by the fact that with decreasing speed cooling becomes more difficult.

If the number of slots in a motor happens to be such that in rewinding it for a greater number of poles, conductors for different phases must be accommodated in common slots, then the insulation necessary between the different phases again takes up space in the slots, and the space factor is still further decreased. If in spite of this some manufacturers make the same type of motor with 8 poles at half the capacity of its 4-pole version, then the explanation is that the laminations of the two motors are different. When a 4-pole motor is to be rewound for 8 poles, the induction in the ring is too small, so that, if the outer diameter of the lamination is kept constant, the rotor's diameter can be increased without the risk of excessive magnetization in the stator-rim. In addition, the end connexions require less space in the direction of the shaft with a larger number of poles, and the length of the core iron can be increased without altering the casting for the stator, and the desired performance can be reached with appropriate slots and winding ; but this cannot be done with a motor-housing originally designed for 4 poles.

Similarly, the conversion of an 8-pole to a 4-pole motor cannot be carried out without checking by calculation. For the induction in an 8-pole lamination can reach a value of 12,000 or even higher and if the flux is kept constant, we would get excessive values such as 24,000 or more. If, on the other hand, we decrease the flux to get the allowed magnetization in the ring, then the torque of the motor will become too small.

In re-building a.c. motors for other pole-numbers, the question of the number of slots requires careful consideration. It may happen that the number of slots in the stator makes symmetrical winding impossible. In this case conversion is inadvisable. The conversion of 24 or 48 slot motors for 6 poles is not wholly satisfactory, though such motors have been built recently. With rotors provided with slip-rings, symmetry is attainable with 2-phase winding ; but such a motor cannot well be used for single phase, since it is difficult to start. With squirrel cage motors it should be considered whether the number of slots in the rotor may not cause difficulties in starting with the changed pole number, or in accelerating to the rated speed.

It has sometimes been tried to connect slipring motors directly to the mains with their rotors short-circuited, using no starters. This is not always successful, since these motors generally have slot numbers not used in squirrel cage motors on account of difficult starting.

An often recurring problem is the use of a 550 volt motor on 380 volt. The possibilities are :

1. To connect the star-connected motor to the mains without any alteration ;
2. To change the connexion from star to delta.
3. To re-wind the stator.
4. To use a transformer between the motor and the mains.

The first solution is always possible. There is no generally valid answer to the question as to what the performance of the motor will be on the smaller voltage ; various types of motors behave differently, according to their design.

The second possibility produces a $\frac{550}{\sqrt{3}} = 320$ volt

motor. To operate this on 380 volts is generally impossible with a modern motor, where magnetizing currents and magnetizations are large. With older types of motor, however, this is often possible.

The third method does not change the characteristics of the machine if the number of turns is correctly determined, and if the original cross-section of copper is adhered to. This is feasible with small and medium-sized motors, but not with large ones.

The fourth method can be used with advantage where the aforementioned methods fail ; an auto-transformer should of course be used.

In view of the inevitable losses associated with this solution it is only justifiable when the motor is not often used, and with multipolar motors when re-winding would be too expensive, and also with large motors when the third method fails.

III. CONVERSION OF D.C. MOTORS TO A.C. GENERATORS.

Small single-phase generators are very much in demand for sound-film equipment, X-ray apparatus, and small three phase motors for stand-by electricity supplies, etc. A frequent and readily effected expedient is to tap the armature winding at the commutator segments in one or three places respectively. This appears to have the additional advantage that d.c. can be taken from the rotor for self-excitation, or possibly even for other purposes. This is a cheap expedient, but has a serious disadvantage. If the rotor supplies a.c., the field strength is considerably decreased which in turn decreases the self excitation. Thus the fall in voltage may make this solution unworkable.

The tapping of d.c. windings is unsatisfactory even with external excitation. Generally the desired a.c. voltage is not obtained unless the excitation is decreased ; it cannot generally be raised above its original value in the d.c. motor. A generator running in a weak field is very sensitive to changes in load and needs continual adjustment. It is more satisfactory in the case of single phase operation to wind only two-thirds of the slots and leave the rest empty, or, with three phases, to use a regular 3-phase or a d.c. winding cut in six places. If this method gives the required 3-phase voltage with the original d.c. winding, then this need not be changed ; if the voltage is higher it is possible to leave out some coils. It is important that all phase-voltages should be equal, and that the phase-angles should, as far as possible, be 120 degrees. Arnold's criteria of maximum voltage variation within 2 per cent and phase-angle deviation of 3 degrees have proved valuable in practice. It is rarely possible to obtain a completely symmetrical winding in such machines, since the number of the d.c. rotor slots is rarely suitable for the purpose.

For satisfactory performance a generator needs a strong field ; therefore motors without auxiliary poles which are usually designed for greater field strengths are as a rule more suitable for conversion into generators than motors having auxiliary poles. If the latter type has to be used and the field strength cannot be raised with the existing coils, it may be possible to put auxiliary turns on to the main poles ; the necessary space is usually available owing to the absence of auxiliary poles.

HOLLAND

Stress-Optical Testing of the Thermal Expansion of Glasses and Metals

By A. A. PADMOS. (From *Philips Research Reports*, Vol. 1, No. 5, November, 1946, pp. 321-330, 6 illustrations.)

IF glass-to-glass, or glass-to-metal joints, made as part of a manufacturing process, are exposed to considerable temperature differences, a periodic check on the thermal expansion of the materials for such joints is necessary to avoid breakages due to relative expansions or contractions. Foremost in mind in this connexion is the manufacture of incandescent lamps, gas discharge lamps, wireless transmitting and receiving valves, and X-ray tubes, etc. One of two methods of checking may be resorted to.

(a) Direct measurement of the linear coefficient of expansion by one of the methods recorded in literature.

(b) Measurement of the stress occurring between the two materials to be joined owing to their different coefficients of expansion, or by measurement of the stress produced by sealing the two materials to a so-called standard material.

It will be shown that the second method should be preferred.

After a glass-to-metal joint has been made and allowed to cool slowly, there will be stresses left at the surface of the joint if the coefficients of expansion of the two materials differ.

Whilst the glass is still soft there will be no stresses in it. Stresses appear as soon as the temperature has fallen so that the glass is no longer a viscous fluid. Fig. 1 shows the expansion curves of glass and metal. If the glass solidifies at the temperature T_2 whilst cooling, a difference of contraction causes a stress, whereas if T_1 is the temperature of solidification, a stress does not form until after that moment.

In the first case, the difference of coefficients of expansion from room temperature to T_2 is decisive for the magnitude of stress present at room temperature. In the second case it is the difference measured along the temperature range from room temperature to T_1. $DC : AB$ is the ratio of the stresses in the two cases. Therefore, not only the expansion curves of the materials must be known but also the solidification temperatures of the glasses used. For glass-to-glass joints stresses will be set up when both glasses have solidified.

Two things are required :—

(a) A knowledge of the trend of expansion according to temperature.

(b) A knowledge of the temperature at which solidification of the glass takes place.

On the basis of practical experience gained with such joints, it is possible to determine, for each type of

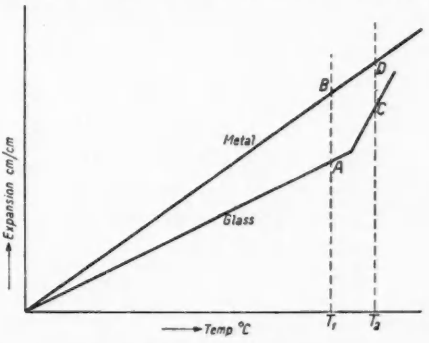


Fig. 1. Expansion curves of glass and metal.

joint, what differences of expansion are permissible, and what differences of expansion will eventually produce cracked glass. While this is obviously a matter to be determined only by accurate observation over a long time, it reveals which materials are best suited for the purpose. Furthermore, a knowledge of the thermal characteristics is not sufficient, the sealing technique, conditions of use, and other factors must be taken into account. The whole problem cannot be solved by calculation for the following reasons :—

(a) The shape of the joint is usually such that a calculation of the stress distribution is out of the question.

(b) The fluctuations of temperature are so poorly defined that little, if any, knowledge can be derived about the stresses they cause which, together with stresses already present, may lead to breakage.

(c) The tensile strength of glass is difficult to determine since it is largely dependent on the nature of the surface and the boundaries, as well as on the duration of the forces.

THE STRESS TEST.

Stress-Testing to ascertain the method of adaption of two glasses to one another was first carried out by J. Smelt. He started from a survey by F. Späte (Glast. Ber. **2**, 1-19, 1924). His investigations led to a method for testing glasses and metals which has been in general use for eight years and gives a perfect insight into the location of the materials in reference to one another. It is well known that stress in glass can be determined and measured by the aid of polarized light. According to classical optics an incident ray is generally refracted, and two polarized rays, with their planes of polarization perpendicular in reference one to another, travel with slightly different velocities in the medium. After passing through a nicol prism, these rays produce interference phenomena from which the phase difference arising between the two rays in the anisotropic medium may be determined quantitatively. This phase difference is proportional to the path of the rays in the medium and the amount of stress in the glass. Which of the two rays is retarded depends upon whether compression or tension is being dealt with. The degree of retardation is expressed in millimicrons per cm. of the path through the medium.

If two materials are sealed together in a suitable shape and the stress is determined in $m\mu$/cm. after cooling, a measure as mentioned above is obtained.

This method has the following advantages compared with a check by means of expansion measurements :

(a) The measurement requires accuracy, but no appreciable experience by the operator.

(b) The precautions necessary to measure the coefficient of expansion, to avoid incorrect readings of the temperature, are unnecessary while other precautions demand a much smaller amount of attention.

(c) The temperature of solidification need not be known, since the stress measurement takes account of both factors determining the stress.

(d) The rate of measurement is greater for different samples tested simultaneously, the time required for the measurement and its preliminaries being short.

(e) Both the glass and the metal are subjected to a treatment similar to that in practice, so that any changes in coefficient of expansion owing to that treatment are already embodied in the measuring results.

The tests apply to three categories of materials:

(a) glasses ;
(b) metals ;
(c) glazes which melt at a low temperature and are used in sealing two glass bodies together.

Procedure is not identical for all three categories, though the same collection of so-called standard glasses is used.

Every joint comes within a certain range of coefficients of expansion and there is a standard glass for each range, which is used indiscriminately.

A plate of approximately 1 × 1 × 0·3 cm. is made of the glass to be tested as well as of the standard glass. This and subsequent operations are done in the flame of a glass-blower's burner. The plates are polished on one side on a rotating fine-grained grindstone and sealed to one another so that one plate of 2 × 1 × 0·3 cm. is obtained. The surfaces are fused for so short a time only that the transition between the two glasses remains visible.

This new plate is put in a furnace the temperature of which is approximately 100 deg. C. higher than the transformation temperature of the glass to be tested. After this it is cooled down at the rate of approximately 2 deg. C. per minute to a temperature at which the removal from the furnace will not produce fresh stresses owing to too rapid cooling (200-250 deg. C.). After cooling there may only remain a permanent stress because of a difference in expansion between the two glasses which is largest at the boundary plane of the two glasses and is measured in the middle of the plate. At the side there are stress-influencing effects.

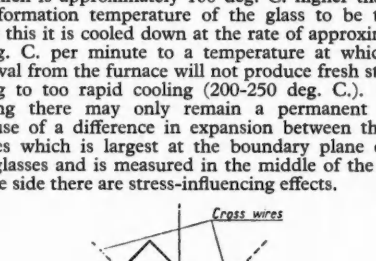


Fig. 2. Method of testing glass plates.

Measurement is by a polarizing microscope with crossed nicol prisms. In the 45 deg. position of the boundary plane in reference to the polarizer and the analizer the field of vision lights up, but this field remains dark with crossed nicol prisms if there is no plate. The plate is orientated as shown in Fig. 2, and the lighting up is caused by the double refraction owing to stress in the glass plate.

The magnitude is measured by placing a compensator in the path of the beam in the microscope-tube, which brings about a larger or smaller amount of double refraction of a known value. A Berek compensator is used for this purpose so adjusted that the double refraction produced by the plate is entirely counteracted and results in the darkening of the centre of the field of vision. If the compensator and plate co-operate, a more intensely luminous effect will result. The plate should then be turned through 90 deg. to render compensation possible.

Taking the thickness of the plate into account, the double refraction, i.e., the stress, can be expressed in $m\mu$/cm. Compression in the standard glass means that the coefficient of expansion of the glass tested is higher than that of the standard glass, and *vice versa*.

If glass *A* causes a stress *a* in the standard glass, and glass *B* a stress *b*, *A* and *B* have mutually a stress *a–b*.

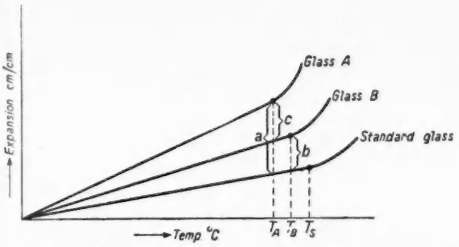


Fig. 3. **Breakdown of subtraction rule when the temperatures of solidification (T_A and T_B) are different.**

That this is not so where the temperatures of solidification are unequal is shown by Fig. 3.

The stress between A and B is represented by c, which is not equal to $a-b$. T_A, T_B and T_C are temperatures of solidification of the glasses A and B and of the standard glass respectively.

In comparison with expansion measurements the time actually required for the examination of glass has been reduced to a minimum. One man having no special training, tests 10 to 15 samples daily.

If a proper limiting-surface is obtained, the degree of accuracy of the measurements of various samples of the same glass amounts to $\pm$ 10 mμ/cm. Expressed in terms of coefficient of expansion this means for lime-glass a degree of accuracy of $\pm$ 0·15 $\times$ 10^{-7}. For measurements of a soda-lime-glass for guiding purposes only, a relation was found according to which 70 mμ/cm. corresponds to a difference of about 1 $\times$ 10^{-7} in coefficient of expansion.

Three categories of metal are used : (a) sheets of a thickness of more than 0·1 cm., but less than 0·3 cm. ; (b) sheets from 0·05 cm. up to 0·1 cm. ; (c) metal wires. Sheet metals thicker than those under (a) are, in principle, sealed onto the standard glasses in the same way as for testing glasses. After being ground the lateral face of the metal is polished and subjected to preliminary treatment as is the practice with metal joints.

Sheet metals as specified under (b) are treated in a different manner. Not the lateral face but the top or the bottom face is ground and polished. An oval drop of glass (length 1 cm., width 0·6 cm., height 0·6 cm.), is sealed onto the polished surface. After the glass has cooled, half of the sample joint is removed by grinding off glass and metal along the major axis of the roughly elliptic shape of the drop. Then a ray of polarized light is allowed to pass in a direction perpendicular to the ground surface and it is possible to measure the " stress " in cm. of path.

The results do not always apply to sheets of greater thickness, but as the test is carried out on a sheet of the thickness actually used, nothing need be known about the behaviour of thicker sheets. Metal wires do not come under the scope of the method described, and other test methods have to be used.

Glazes are used where glasses of a higher softening point have to be sealed to one another whilst the parts inside the lamp or valve should be kept as cool as possible. When testing the glazes by sealing them to the standard glass, another method has to be applied owing to the great difference of softening temperatures. In a hard-glass tube of about 1 cm. inside diameter and 0·1 cm wall thickness, coated inside with loose metallic foil (Cu, Al), a plate of standard glass is placed (about 0·5 cm. thick), and upon this a layer of glaze-powder is strewn (again about 0·5 cm high). After placing this assembly on a heat-resisting plate, fusing is carried out at the temperature applied for the actual operation in production. After cooling down the cylindrical fusion product is ejected from the tube, two parallel flat faces are ground on the surface of the cylinder, and the sample is ready for stress measurement. Troubles arising from the roughness of the ground surfaces are obviated by immersion of the glass object in benzene or some other liquid whose refractive index approaches that of glass. The following table gives an idea of the order of magnitude of the permissible stresses in some more generally interesting cases.

Fig. 4 shows the variations of the values characterizing a certain glass taken from a particular tank. Of the three broken lines the top and bottom plot indicate the extreme values, and the middle plot the arithmetical mean. Once every week the three values were determined and entered into the graph. The figures on the mean value line indicate the number of drawings. The horizontal dotted line represents the monthly, the horizontal full line the three-monthly, average.

Kind of glass or metal	Admissible stress in mμ/cm in corresponding standard glass. C = compressive stress ; T = tensile stress	Remarks
Lime-glass for incandescent lamps	300 T-200 C in standard glass X	in normal cases
ditto	300 T- 0 in standard glass X	for special difficult cases
Lead-glass for lamp stems	200 T-250 C in standard glass Y	in normal cases
Alkali alumo boro silicate glass	200 T-100 C in standard glass Z	for difficult glass-metal joints
Fernico (iron-nickel-cobalt alloy)	0 -300 C in standard glass Z	for normal fernico cases, thickness 0·15 cm.
Chrome-iron	200 C-500 C in standard glass Y	for normal chrome-iron cases, thickness 0·15 cm.

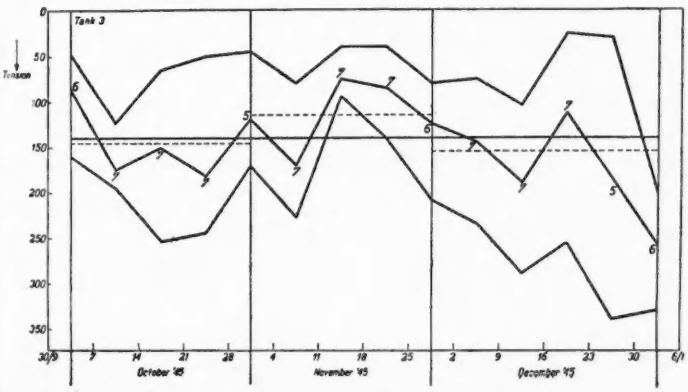


Fig. 4. **Example of a graph showing variation of the tension with time for samples taken at regular intervals from one and the same tank.**

The Cyclone Dust Separator

By E. FEIFEL. (From *Maschinenbau und Wärmewirtschaft*, Vol. 1, No. 1/2, July/August, 1946, pp. 36-41, 16 illustrations.)

IN a wide sense cyclone extraction is the separation of mixtures, which usually consist of a gaseous carrier and finely dispersed solid or liquid particles, by the action of centrifugal force in a centrifuge having no moving parts. Theoretically, the flow fixture can be obtained by superimposing a vortex on a sink, referred to as a vortex-sink. (Fig. 1.)

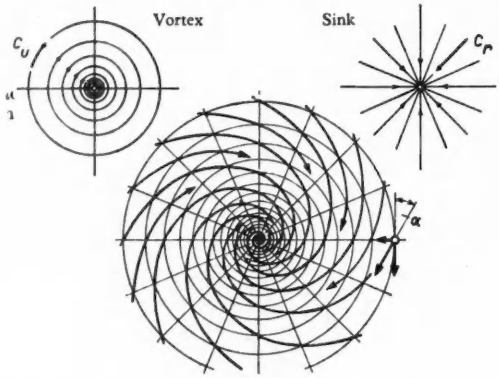


Fig. 1.

The only definite attempt to evolve a cyclone theory known in literature is the double-vortex theory by Van Tongeren which, however, does not take account of extraction efficiency and the law of similarity, etc. Also, it is based on an unfortunate confusion between the gas stream filament and the dust path.

To obtain a mathematical insight into the process of separation, it was necessary to create a new basis and reduce observations to a systematical order.

From an inspection of photographs of spiral nebulæ, one perceives a similarity to the flow depicted in Fig. 1. In the extractor, however, the continuous delivery of gas requires an additional meridional flow, perpendicular to the plane of the vortex-sink. On a terrestrial scale, the physical process of the natural cyclone is

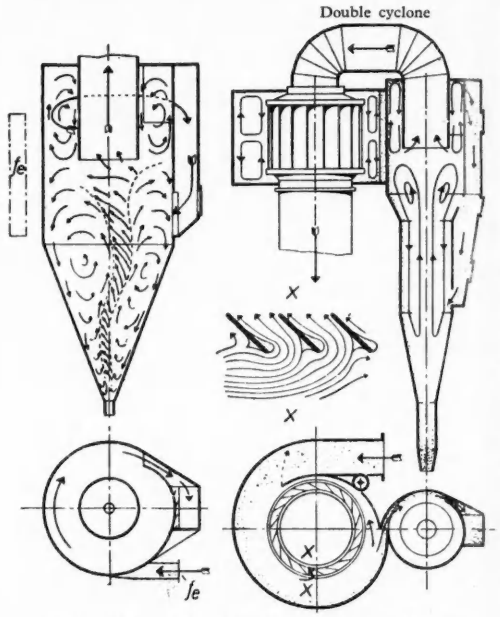


Fig. 2. **Airflow in a cyclone according to van Tongeren.**

identical to that of the ideal centrifugal separator with tangential inlet.

It is necessary, therefore, to transfer the flow pattern from the unrestricted medium of the atmosphere to the scales obtaining in the laboratory. The frictional influences, due to the walls and the bottom of the extractor, disturb the ideal flow pattern and the problem of utilizing these disturbing flows to serve the purpose has been dealt with in a definite way.

Resulting from a fundamental and simple laboratory experiment on the discharge flow with change of momentum (Fig. 3), it has been established that from the total cross-sectional area of the outlet pipe only an annular area of the radial width $(r_a - r_i)$ is utilized.

The result of preliminary development work was an extractor-cell consisting of a cylindrical main chamber, separated by a flat plate from a dust collecting space beneath it, having inlet and outlet pipe areas in accordance with vortex-sink requirements, a meridional main flow in the chamber, a rotational flow of the contents of the chamber which is dece'erated near its walls, a downward flow in the vortex cone which unites with the flow down the wall to form a "squeeze-flow" and then rises in the cone envelope to the outlet pipe through which it passes with the main flow.

It is inherent in the centrifugal principle that small separators give higher collecting efficiency than large ones. For large gas quantities it is necessary to employ a great number of small cyclones working in parallel for high efficiency. Since any cyclone of such a group determines the grain size of separation, the term "vortex sieve" has been adopted.

After having solved the problems of switching individual cyclones in parallel into the sieve, the I.G.

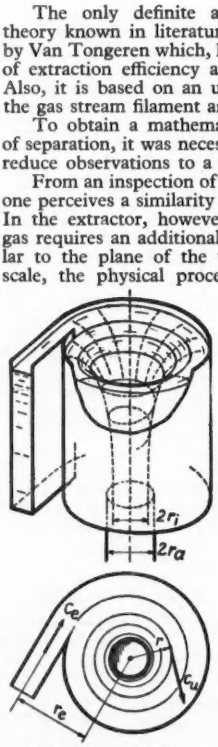


Fig. 3. **Vortex-sink in an open test vessel with tangential water inlet.**

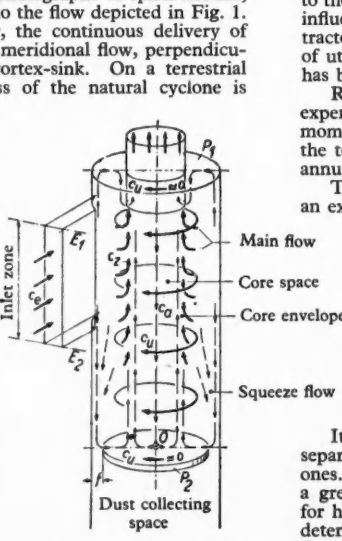


Fig. 4. **Flow components in the cylindrical cyclone with annular dust withdrawal slot.**

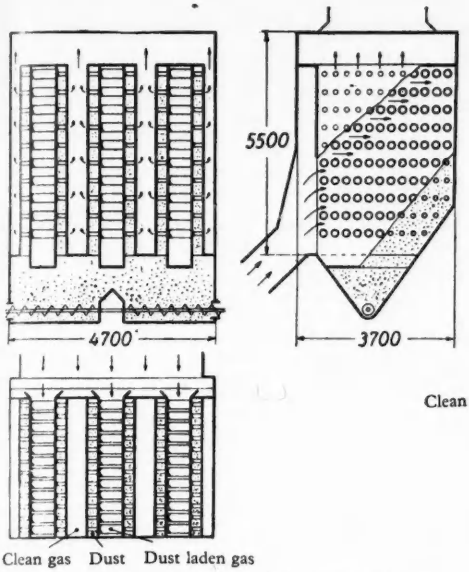


Fig. 5. **Diagrammatic view of the first large-size vortex sieve.**

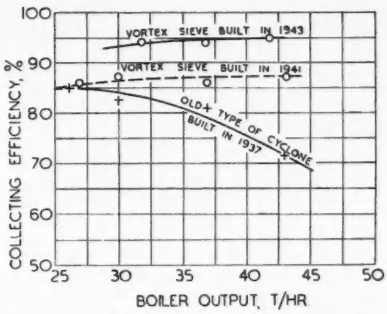
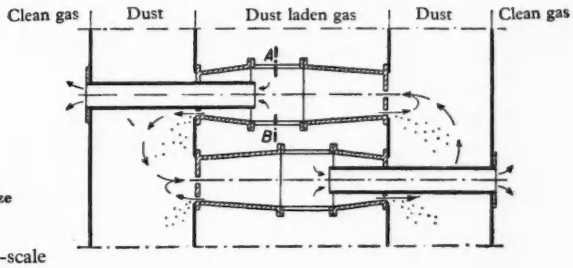


Fig. 6. **Test results on vortex sieve according to Fig. 5.**



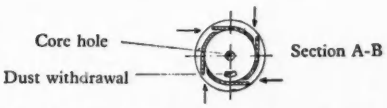


Fig. 8. **Diagram of cells of the vortex-sieve built in 1943.** (See Fig. 6.)

Farbenindustrie was prepared to undertake large-scale tests at their power station Bitterfeld. The Benson boiler at this station used rather low-grade fuel, producing very fine fly-ash. The cyclone installed in 1937 by the original contractor for the whole plant was replaced by a vortex-sieve consisting of 300 small cyclones horizontally arranged. As the forces of gravity are negligible compared with other forces acting on the dust particles, such an arrangement results in a particularly simple lay-out. The tests were so promising that I.G. Farben agreed to the replacement of the experimental sieve after 12 months' service by an improved one, again consisting of 300 cells. The improvements incorporated are now accepted in modern design, and are essentially due to the following changes in the operating principle shown in Fig. 4, which, for most purposes, is superseded :—The annular slot between the extractor wall and the collecting space has been replaced by a relatively small withdrawal slot near the wall and the collecting space is subjected to a high vacuum (Fig. 7). By providing a " core " hole in the bottom plate, a return flow from the dust collecting space is introduced which returns a large amount of the dust to the cyclone chamber.

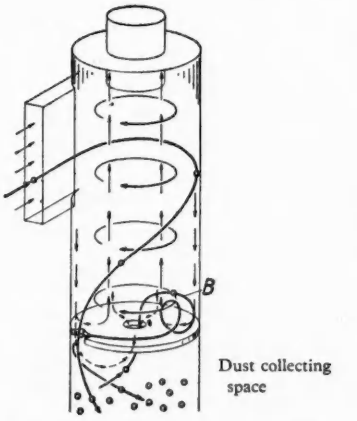


Fig. 7. **Cylindrical cyclone with dust withdrawal slot near the wall, and core hole in plate bottom (partial return flow).**

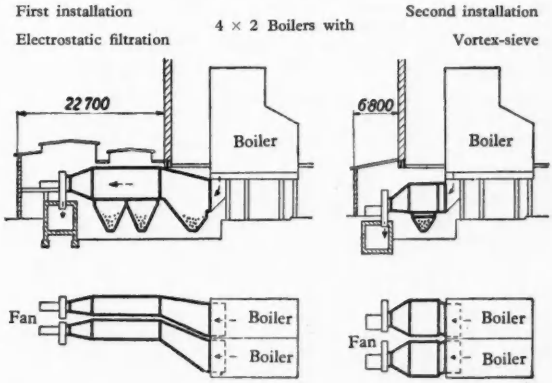


Fig. 9. **Space requirements of electrostatic filtration and vortex-sieve for identical conditions.**

The task of keeping this dust away from the clean gas outlet pipe is completely solved by correctly dimensioning the length of the separator. The natural cyclone offers a solution of perfect simplicity. It can be observed that foreign bodies lifted up by a natural cyclone are thrown out at some height from the earth's surface and, in our case, this can be achieved by developing a "cyclone within the cyclone," realizable by correctly determining the height of the extractor cell.

By this development a stong competition of the cyclone dust extractor with extractors based on electrostatic principles has risen in all fields of chemical and mechanical technology. Problems of oil and moisture separation from steam, of de-foaming, and of cleaning of generator gas, have been successfully solved.

For the purpose of flue gas dust removal the I.G. Farben profited from the test plant at Bitterfeld. One of their power plants which in the first installation had eight electrostatic extractors to deal with 1,000,000 m^3/hr. of flue gas is just receiving a second installation of vortex-sieves to deal with a similar quantity. This decision becomes understandable on hand of Fig. 9. (See also "Test Results with a Feifel Cyclone," Mitteilung, No. 92 der Vereinigung der Grosskesselbesitzer E. V. Berlin, by G. Starke).

The centrifugal type of extractor can also be used with advantage to clean the intake air of all types of automotive engines. The use of the cyclone for this purpose met with much disapproval and prejudice. In spite of this, however, the Viennese type of cylindrical extractor chamber found extensive use and is now fully accepted. The exhaust gases can be used for evacuating the contents of the internal dust collecting space. Such plant once installed requires no further attention.

RUSSIA

Use of Natural Gas for Locomotives

By A. Poido and A. Mironov. (From *Zheleznodorozhnii Transport*, No. 11/12, 1946, pp. 69-71, 5 illustrations.)

The construction of several natural gas pipe lines in the vicinity of railway lines has created very favourable conditions for the employment of this gas as locomotive fuel in Russia. A typical pipe line is that from Saratov to Moscow. It is 850 km. in length and delivers 1·5 million cu. m. of gas per day, which is equivalent to 400,000 tons of oil per annum.

To adapt a locomotive to natural gas fuel, a special tender to carry the requisite number of gas bottles must be provided. The design of such a tender is well advanced, and it is intended to employ an operating gas pressure of 80 kg. per sq. cm. The bottles would be suitable for an even higher pressure up to 100-110 kg. per sq. cm., but this would require the erection of special charging plants which does not yet appear justifiable.

The operation of a Diesel with mixed fuel (gas plus oil) is based upon the difference in the respective ignition temperatures of oil-air and gas-air mixtures. Through the inlet valve a prepared mixture of gas and air is admitted which has a very high temperature of self-ignition. Towards the end of the compression period a small quantity of oil (10-15 per cent of the oil normally injected in full Diesel operation) is injected. This oil ignites and causes combustion of the entire mixture contained in the cylinder. Subsequent phases of the combustion cycle are the same as with straight Diesel operation and it is therefore not necessary to alter the compression ratio when changing over from diesel fuel to mixed-fuel operation.

Control of the mixed-fuel engine is effected by the action of a speed governor upon both the gas throttle and the fuel oil pump. Provision is made for starting the engine on oil alone and for limiting the gas supply to 50 per cent of the combined fuel supply when the engine is idling. Load pick-up is then affected by increasing the gas supply whilst the oil supply remains unchanged. Starting of the engine is not therefore different from that of an ordinary diesel.

The service weight of the tender of a natural gas-driven locomotive is 74 tons. There are 57 gas bottles, each of 11 m. length and 320 mm. diameter. Each bottle weighs 870 kg. has a volume of 0·77 cu. m. and is designed to withstand an operating pressure of 110 kg. per sq. cm. although the pressure at present is 50-80 kg. per sq. cm.

The firebox of a natural gas fired steam locomotive is identical with that of an oil fired locomotive ; but the burners are different. There are three gas burners of the type illustrated in Fig. 1, each one having a

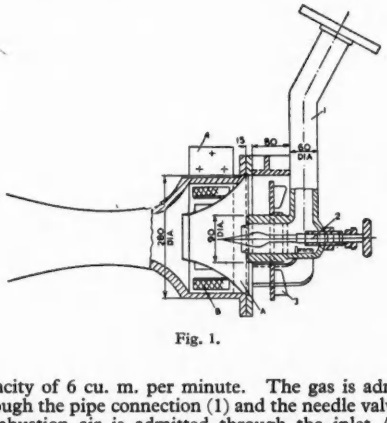


Fig. 1.

capacity of 6 cu. m. per minute. The gas is admitted through the pipe connection (1) and the needle valve (2). Combustion air is admitted through the inlet A, the opening of which is adjusted by the disk (3) seated on the nozzle body, and through the register B controlled by the damper (4). Gas pressure at the burner nozzle is 1·4 to 1·5 atmospheres, and the excess air factor ranges from 1·4 to 1·6. To improve combustion conditions in the firebox, either 10-15 per cent coal dust or 10-15 per cent coal are fired with the gas. The control of gas and air admission is similar to that employed with oil fuel. To increase the operating range without refueling, the ordinary tender, in addition to the special tender, is also provided with 28 gas bottles having a total capacity of 10 cu. m. With a gas pressure of 50 atmospheres the operating range of the diesel locomotive is 330 km. ; and with 110 atmospheres the range is increased to 660 km. In the case of the gas fired steam locomotive the operating range on gas is 119 km. with a gas pressure of 50 atmospheres, and 238 km. with 100 atmospheres gas pressure.

Electrokinetic Phenomena and Their Application in Soil Mechanics

By W. SCHAAD and R. HAEFELI. (From *Schweizerische Bauzeitung*, Vol. 65, Nos. 16, 17, and 18, 1947, pp. 216-217, 223-226, and 235-238, respectively ; 18 illustrations.)

IN view of the difficulties experienced in the drainage of fine-grained soils and of attempts made in Germany to overcome such difficulties by employing electrokinetic methods, a systematic investigation of the problems involved was undertaken at the Swiss Federal Technical College, Zürich. The principle of activating the ground water by means of a direct electric current is illustrated in Fig. 1. By inserting one electrode into a well tube having a filter point, sinking a second electrode at another point, and connecting them with a d.c. source, an electric field is produced in the soil. At the same time a portion of the electric current flowing from the positive to the negative electrode passes through the ground-water and the soil submerged in the ground-water.

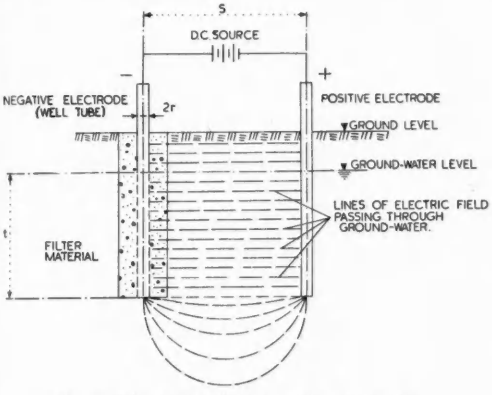


Fig. 1. Diagram of electrosmotic well circuit.

In the case of fine-grained soils—impossible or difficult to drain by any of the usual mechanical methods—this electric current produces the phenomenon of electrosmosis in the capillaries of the soil, thereby causing the water particles to be transported through the interstices and in the direction of the electric field. By connecting the electrode in the well tube with the positive polarity, an amount of water is transported to the well greatly in excess of that flowing under the influence of the existing hydraulic head.

This phenomenon is due to the fact that an electric potential difference exists at the interface of two media contacting each other ; and this potential difference is particularly pronounced in the case of two metals of widely different electrical potential immersed in a common bath of electrolyte. An analogous potential difference exists at the interface of two contacting non-metallic media. Thus at the interface of water and soil a potential difference is caused in the boundary layer which is known as the electrokinetic potential or "ζ" potential. In this case the medium having the larger dielectric constant will assume positive polarity with respect to the medium having the lower dielectric constant. If a voltage is applied to electrodes placed at the ends of a capillary, then in the case of water the electric field drives the positive boundary charges in the water from the positive to the negative electrode, thus producing the migration of water through the capillary, which process is known as electrosmosis.

Fig. 2 outlines a capillary of electrically non-conductive material subjected to a static pressure

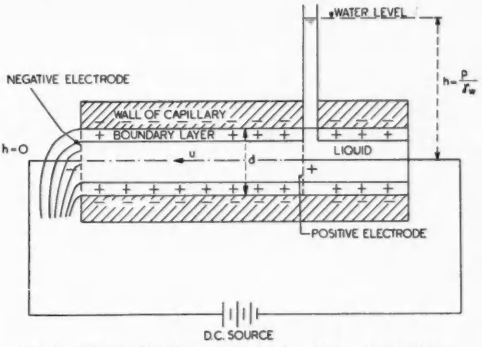


Fig. 2. Hydraulic-electrosmotic flow through capillary.

$p = \gamma_w \cdot h$, to the ends of which a voltage U is applied to produce the current I. According to Helmholtz-Perrin-Smoluchowski the velocity of fluid flow through the capillary is given by

$$u = \frac{d^2}{32\eta}\frac{p}{l} + \zeta\frac{\rho_w D}{4\pi\eta} j \quad .. \quad (1)$$

where u is the mean velocity of flow of the fluid, d is the diameter of the capillary, η is the viscosity of the fluid, p is the pressure difference given by $\gamma_w h$, h is the static load, l is the length of the capillary, ζ is the electrokinetic potential, ρ_w is the specific resistance of the fluid, D is the dielectric constant of the fluid and j is the current density in the capillary. This equation can also be given in the form

$$u = u_0 + u_1 \quad .. \quad .. \quad .. \quad (2)$$

where it will be seen that u_0 represents the expression for laminar flow as established by Poiseuille, whilst u_1 is the velocity of flow due to the action of the electric current. In order to make this equation applicable to the flow of fluids through finely dispersed systems, the mean velocity of flow u must be replaced by the filter flow velocity v_F based upon the total flow area of the porous mass. Analogous with equation (2) the expression for the laminar filter flow can be written thus :

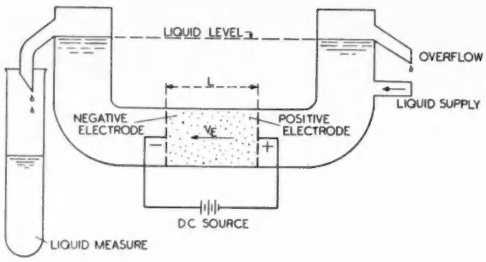
$$v_F = v_D + v_E = k\mathfrak{J} + k_E E \quad .. \quad (3)$$

where v_F is the total velocity of filter flow, v_D is the velocity of filter flow according to Darcy, v_E is the electrosmotic velocity of filtration, k is the permeability constant, $\mathfrak{J}$ is the hydraulic pressure gradient, E is the strength of the electric field and k_E is the electrosmotic constant defined as the velocity of filter flow prevailing with an electric field strength of $E = 1$ volt per cm.

As it is difficult to form a mechanistic concept of the electrosmotic constant, the author proposes a different basis for the evaluation of the electrosmotic effect in porous matter. This is the electrosmotic head H_E or the specific electrosmotic head h_E. According to Fig. 5 the electrosmotic head H_E is the differential head, expressed in cm., produced by applying the potential difference of 1 volt to a sample of the material in question. Once the electrosmotic head has established itself in the material, equilibrium exists between it and the hydrostatic head. For $v_F = 0$, equation (3) becomes

$$v_F = -k\mathfrak{J} + k_E E = -k\frac{H_E}{L} + k_E\frac{U}{L} = 0$$

where L is the length of the test piece, and therefore



$v_E = k_E \frac{U}{L}$ velocity of electrosmotic filtration.

$Q_E = k_E \frac{F}{L} U = k_E \rho I$ electrosmotic liquid delivery.

Fig. 3. Principle of electrosmotic flow measurement.

$$H_E = \frac{k_E}{k} U = h_E U \quad .. \quad .. \quad (4)$$

where h_E is the specific electrosmotic head, expressed in cm. per volt. For $U = 1$ volt, equation (4) yields $H_E = h_E \times 1$ volt $= (k_E/k) \times 1$ volt ; the factor h_E is thus seen to furnish a measure of the extent to which an existing fluid flow can be increased by the electrosmotic method, that is to say, h_E represents a measure of the electrosmotic effect. On the basis of equation (3) the hydraulic-osmotic flow in c.g.s. units is expressed by the differential equation

$$k \Delta \Phi_H + D_B \Delta \Phi_E = -4 \pi \epsilon \quad .. \quad (5)$$

where Δ is Laplace's Operator, Φ_H is the hydraulic potential of the ground-water flow, D_B is the dielectric constant of the saturated soil, Φ_E is the electric potential, and ϵ is the density of the electric charge per unit of space. The quantity of liquid Q_E transported by electrosmotic action is given by $Q_E = k_E \rho I$, where ρ is the specific electric resistance of the soil and I is the amperage.

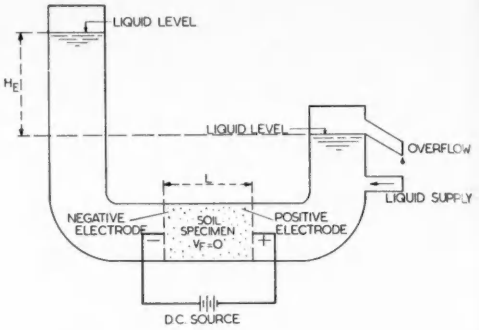
For the case illustrated in Fig. 1, the following simplified formulæ are arrived at on the basis of equations (1) to (5).

Electrical Resistance.

$$R \sim \frac{\rho}{\pi t} \ln \left(\frac{s}{r} \right) \text{(Ohm.)} \quad .. \quad (6)$$

Amperage.

$$I = \frac{U}{R} \sim \frac{\pi U t}{\rho} \cdot \frac{1}{\ln (s/r)} \text{ (Amp.)} \quad .. \quad (7)$$



Head $H_E = \frac{k_E}{k} U$

Fig. 5. Principle of electrosmotic head measurement.

Power Consumption.

$$N = U I \sim \frac{\pi U^2 t}{\rho} \cdot \frac{1}{\ln (s/r)} \text{ (Watt.)} \quad (8)$$

Electrosmotic Delivery.

$$Q = k_E \rho \,.\, I \sim k_E \,.\, \pi \, U \, t \frac{1}{\ln (s/r)} \text{ (cm}^3\text{/second)} \quad .. \quad (9)$$

where ρ is the specific resistance of the soil in saturated condition ;

t is the length of electrode immersed in the ground-water ;

s is the distance between the electrodes ;

r is the radius of the electrodes ;

U is the voltage.

A number of tests were carried out by the authors for the purpose of proving the validity of equation (3) with regard to finely dispersed loose material and to establish a simple method for experimentally determining numerical values for k_E and h_E of a given material.

The constant k_E was determined as indicated in Figs. 3 and 4, the latter showing the salient features of the apparatus used. The head h_E was found in similar manner, the principle of measurement being indicated in Fig. 5, while the operating principle of the apparatus used is outlined in Fig. 6.

The original article contains a certain amount of empirical data obtained in this manner. It also describes an experimental soil draining scheme which proved the simplicity and low operating cost of the electrosmotic method. An extensive bibliography is also given.

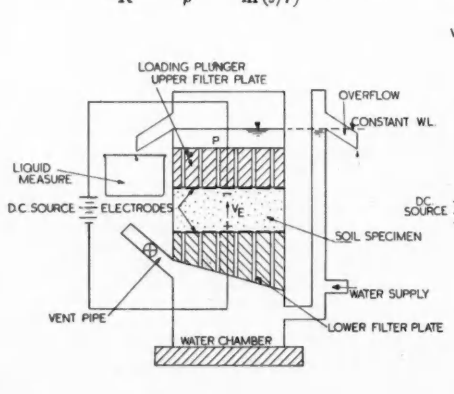


Fig. 4. (left) Electrosmotic test device set up for flow measurement.

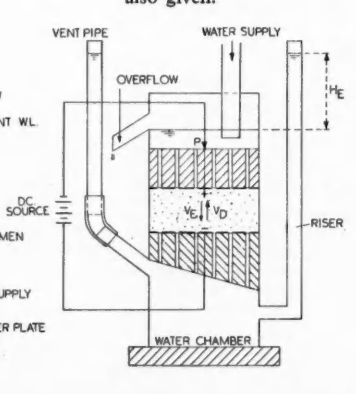


Fig. 6. (right) Electrosmotic test device set up for static head measurement.

Comparing Plastics

By C. E. Staff, J. M. Hill Jr. and H. M. Quackenbos Jr. (From *Machine Design*, Vol. 19, No. 7, July, 1947, pp. 112-116, 6 illustrations.)

With each year there is an increasing use of plastics, in industrial equipment and home appliances. Agitators for washing machines, telephone hand-sets, spinning buckets in the rayon industry, distributor heads, and gears are a few examples of this trend. Among the properties of plastics that have made possible these uses are :—

1. Easy fabrication. Moulding powders are readily formed in steel moulds to produce complicated parts to close tolerances without the need of an expensive finishing operation. Large and small irregular shapes are easily produced from plastics laminates at rapid rates.
2. Low specific gravity, averaging 1·4 and rarely exceeding 2·0.
3. Chemical resistance.
4. Superior dielectric properties.
5. Appearance—gloss, transparent or warm colour.
6. Feel—warm due to low thermal conductivity.
7. Quietness in handling because of high damping.

In questions relating to machine design all the attributes listed above may influence the designer to prefer plastics for the part under consideration but his final decision may often be based on the cost in combination with purely mechanical properties, like flexural strength, afforded by the plastics being considered. The cost of a plastics part in comparison with the cost of a similar part in another material must be solved as a specific problem which can best be answered by estimates from fabricators. The purpose of this article is to provide a ready reference of these mechanical properties that have such an important bearing on the designer's decision.

Data on the mechanical properties of plastics types have been slow in evolving but they are now fairly complete after the rapid progress of the past six years. However, they are scattered widely through the literature so that a compilation in one place is appropriate at this time.

The values given in Table I and II are averages determined at standard testing conditions of 77 deg. F. and 50 per cent relative humidity unless otherwise stated. A steel and an aluminium alloy are included for comparison. It is believed that no detailed explanation is needed of either the practical significance or the method of measuring the properties listed. The references at the end will supply detailed information if such is desired. However, it is thought desirable to discuss a few of these materials and their properties :

THREE BASIC GROUPS OF PLASTICS

Materials : Although there are hundreds of plastics in commercial use they are adequately represented by the several materials listed. These have been divided into three basic types :

Thermosetting : Phenolics have been chosen for the table. However, materials based on melamine resin and on urea resin are similar to the phenolic materials containing the same fillers. The lighter colour of these resins permits the production of pastel moulding.

Thermoplastic : Modified polystyrenes have been developed to improve the heat resistance as much as 30 deg. C. and reduce somewhat the brittleness of polystyrene. The cellulose acetate listed is a medium grade. Harder acetate has a higher tensile strength, higher modulus of elasticity and less elongation under tension. Softer acetate varies from medium acetate in the opposite direction. Ethyl cellulose, cellulose acetate-butyrate and cellulose propionate may also vary in properties according to the formulation. Generally medium grades resemble the medium grade of cellulose acetate. The properties of thermoplastics vary with the method of moulding. The figures given are conservative ones for injection-moulded samples. With compression moulding there is usually a moderate decline in mechanical strength.

Table I

Comparison of Beams of Same Width and Load Capacity.

Material	Depth	Weight	Stiffness	Flexural Work, Unnotched (Impact Resistance
Steel	1·0	1·0	1·0	1·0
Woodflour-Phenolic	2·8	0·49	0·73	0·08
Canvas Laminate ..	1·9	0·33	0·30	0·5
Aluminium ..	1·0	0·34	0·35	0·7

The polymethacrylate in the tabulation is a typical one ; properties vary with formulation. Rigid vinyl plastic sheet possesses similar mechanical properties. Thermoplastics like polyethylene and highly plasticized vinyls cannot be called rigid, because of their low modulus of elasticity, and have been omitted.

Laminates : Grades XX and L are standard mechanical laminates containing about 50 per cent phenolic resin. Other resins give somewhat similar laminates. The Fiberglas laminate is bonded with a phenolic resin. Properties will vary somewhat with resin type and amount.

For the design engineer, an understanding of the physical properties of plastics is perhaps more difficult than is the case with metals. Certainly plastics do not follow the metallurgical rules of metals where changes in physical properties are concerned. Examples of variations follow :

Stress-Strain Relations : Tensile stress-strain curves for all rigid plastics except cellulosic compounds are shown in Fig. 1. The curve for cellulose acetate is shown in Fig. 2. As indicated in these illustrations if a 0·2 per cent offset point exists in tension or flexure, it is at least 60 per cent of the ultimate strength for both types. If the compressive strength is much higher than the tensile strength the 0·2 per cent offset stress in compression is only 30 to 50 per cent of the ultimate compressive strength and there is much more plastic strain than in tension ; otherwise tensile and compressive stress-strain curves are similar. Modulus of elasticity is nearly constant (usually ± 20 per cent) whether loading is tensile, flexural or compressive for all materials.

Notch Sensitivity : This value describes the weakening effect in flexural loading of a notch 0·1 inch deep with a radius 0·01 inch at the bottom, and is given by

$$\text{Notch Sensitivity} = P/P_n$$

where P is the breaking load for a 0·4 inch thick flat bar, and P_n is the breaking load for a 0·5 inch thick bar with a 0·1 inch deep notch. Notch sensitivity tends to reduce all dynamic and static strengths where the part contains small holes, sharp corners, sudden changes in section, screw threads, etc. Thermoplastics are much more notch sensitive when the notch is cut or milled than when it is moulded.

Impact Resistance : The Izod impact test on a $\frac{1}{2}$ by $\frac{1}{2}$ inch specimen containing a standard milled notch, of the dimensions given under Notch Sensitivity in Table II, is often a misleading criterion of the capabilities of a material. A more satisfactory value is flexural work to break (i.e., the area under a flexural load-deflection curve). The value for an unnotched bar, $\frac{1}{2}$ by $\frac{1}{2}$ inch on a 4 inch span, applies in practice where the moulded object contains no notches or

equivalents in the form of sharp corners, etc. Flexural work to break, notched, is determined under similar conditions, except that the bar contains a standard notch,

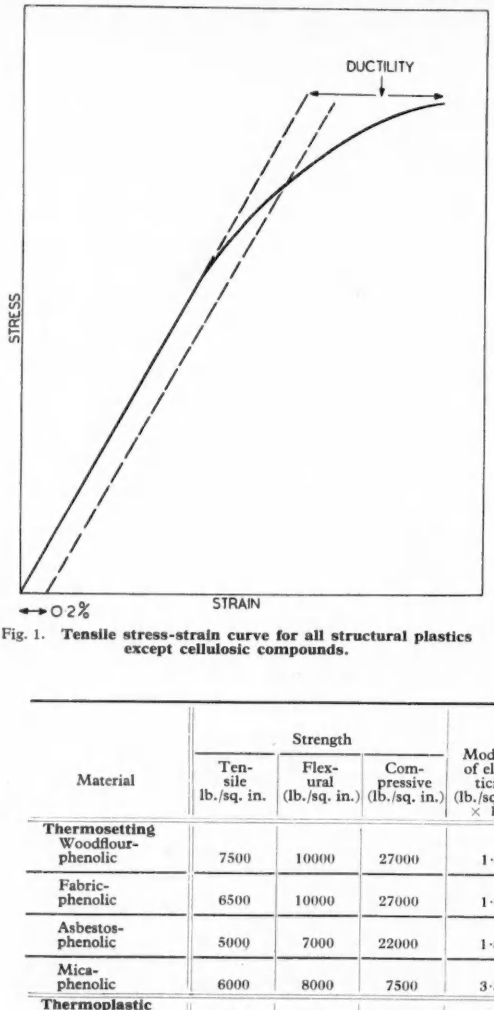


Fig. 1. **Tensile stress-strain curve for all structural plastics except cellulosic compounds.**

and it is a measure of resistance to impact of objects that do contain notches and equivalents. These two values of work to break provide quite a different evaluation than the Izod test and they demonstrate clearly the weakening caused by a notch when the notch sensitivity is high. However, where the ductility is high, flexural work may not correspond so closely with actual resistance to impact. The flexural work to break for steel and

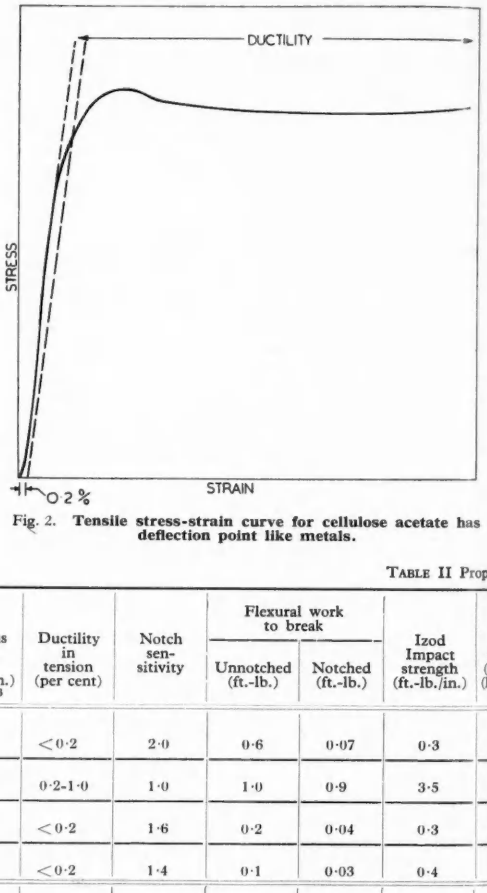


Fig. 2. **Tensile stress-strain curve for cellulose acetate has deflection point like metals.**

TABLE II Proper Typical Plas

Material	Strength			Modulus of elasticity (lb./sq. in.) × 10^{-6}	Ductility in tension (per cent)	Notch sensitivity	Flexural work to break		Izod Impact strength (ft.-lb./in.)	Fa strng (ba (lb.	Hardn rockwel or Brinel
	Tensile lb./sq. in.	Flexural (lb./sq. in.)	Compressive (lb./sq. in.)				Unnotched (ft.-lb.)	Notched (ft.-lb.)			
Thermosetting											
Woodflour-phenolic	7500	10000	27000	1·0	<0·2	2·0	0·6	0·07	0·3		M-1
Fabric-phenolic	6500	10000	27000	1·0	0·2-1·0	1·0	1·0	0·9	3·5		M-1
Asbestos-phenolic	5000	7000	22000	1·8	<0·2	1·6	0·2	0·04	0·3		M-1
Mica-phenolic	6000	8000	7500	3·5	<0·2	1·4	0·1	0·03	0·4		M-1
Thermoplastic											
Polystyrene	6000	15000	13000	0·5	0-0·5	1·0	3·5	0·5	0·3		M-8
Cellulose-acetate	4500	7000	14000	0·2	36	1·0	—	—	1·4		M-5
Poly-methacrylate	8000	12000	12000	0·4	3	—	—	—	0·45		M-8
Laminates											
Paper Laminate, XX	17000	18000	24000	1·5	1·0	2·0	1·9	0·3	2·2		M-1
Canvas Laminate, L	16000	22000	26000	1·3	0·8	1·4	4·9	0·6	4·4		M-1
Fiberglas Laminate	39000	60000	28000	2·4	0·2-1·0	1·4	7	2	22		—
Metals											
Steel, SAE 1025	80000	—	—	30	18	1·0	21	—	+50		B-1
Aluminium 17ST	60000	—	—	10	20	1·0	16	—	—		B-1

*Average data on each material classification are given.

aluminium is the approximate work to cause a yield of 0·2 inch at the centre of a $\frac{1}{2}$ by $\frac{1}{2}$ inch bar on a 4 inch span. Both have, practically, failed at that stage.

FATIGUE STRENGTH : With metals, the fatigue stress to cause failure often becomes constant after 10^6 cycles and this stress is then called the fatigue strength or endurance limit. With plastics the endurance limit is often not sharply defined and there is a tendency for the stress to cause failure to fall slowly after 10^6 cycles. The fatigue strength given is based on experiments carried to 10^8 cycles at speeds of stressing varying from 1800 to 10,000 r.p.m. Speed of testing may not greatly affect fatigue strength. Some plastics tend to rise in temperature during fatigue loading because of high internal damping ; consequently the modulus of elasticity may fall somewhat. This is more marked with the thermoplastics.

DAMPING CAPACITY : The data presented are calculated from the decay of vibrations corresponding to low stresses. Where the stress is sustained at a level near the fatigue strength it appears that damping capacity may be much higher. However, the only available data are too few for comparison.

The possession of a high damping capacity is desirable where noise must be reduced and for this reason plastics gears, are often preferred to metal gears or are used in combination with metal gears. High damping capacity is also an advantage when vibratory loads at the resonant frequency must be resisted. At resonance a low applied load can cause a high stress. For a given load this stress is higher the lower the damping capacity. High damping capacity thus provides a factor of safety against failure at resonance.

SPECIFIC GRAVITY : If a plastics object is to be as strong as if it were metal it is necessary to use much more material. However, the low specific gravity of the plastic means that there may be no actual increase in weight and in some instances a reduction.

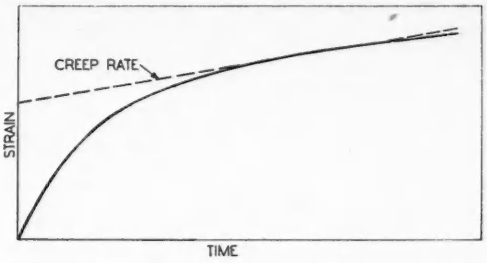


Fig. 3. Creep curve for plastics at room temperature. Period of rapid creep is followed with phase in which creep is almost linear with time.

For a member under tension the area of wood-flour phenolic material would have to be 80,000/75,000 or 10·7 times that of steel and the weight would be 10·7 (1·36/7·8) or 1·85 times as much. Similarly the area and weight ratios would be 5·0 and 0·86, respectively, for canvas laminate to steel and 1·33 and 0·46 for aluminium to steel. These members having strengths equal to that of a steel member would exhibit the following tensile stiffnesses (steel being 1·0) : wood-flour phenolic 10·7 (1·0/30) or 0·36, canvas laminate 0·22, aluminium 0·44.

Similar comparison can be made for flexural loading. If a practical flexural strength of steel is assumed to be equal to the tensile strength (80,000 lb/sq. in.) the depth of a member of equal width and equal strength for wood-flour phenolic material having a flexural strength of 10,000 lb./sq. in. would be $(80{,}000/10{,}000)^{0.5}$ or 2·8 times as much.

The weight would be 2·8 (1·36/7·8) or 0·49 as much for the plastic as for steel. Stiffness, being proportional

Typical Plastics

Hardness rockwell M or Brinell B	Poisson's ratio	Specific gravity	Long time tensile at 77 deg. F. Creep strength (lb./sq. in.)	Long time tensile at 77 deg. F. Creep rate (%/1000 hr)	Strength at higher temperatures Temp. (deg. F.)	Strength at higher temperatures Creep (lb./sq. in.)	Strength at higher temperatures Tensile (lb./sq. in.)	Water distortion 21 days in H_2O (% length chg.)	Coefficient of thermal expansion ($\times 10^{-6}$/deg. C.)
M-115	0·3	1·36	2500	0·04	192	1300	6500	0·1	35
M-110	0·3	1·38	2200	0·06	192	1300	6000	0·2	20
M-112	0·3	1·9	2000	0·02	192	1300	5000	0·01	18
M-107	0·2	1·88	1800	0·005	192	1300	5000	0·01	18
M-87	0·3	1·07	+1000	—	125	<1000	5000	0·004	70
M-56	—	1·28	1000	0·1	125	—	2500	0·4	120
M-80	0·4	1·18	+1000	—	125	<1000	4000	0·04	80
M-112	—	1·34	8000	0·1	192	5000	13000	2·0	—
M-106	—	1·34	8000	0·05	—	—	14000	0·4	—
—	—	1·7	—	—	—	—	—	≤0·2	—
B-163	0·3	7·8	50000	negligible	800	18000	—	—	11
B-15	0·3	2·7	30000	negligible	—	—	—	—	24

to the modulus multiplied by the cube of depth, is $(1{\cdot}0\times10^6\times2{\cdot}8^3)/(30\times10^6\times1{\cdot}0^3)$ or 0·73 for the plastics, compared with 1·0 for steel. Flexural work, being proportional to depth, is $2{\cdot}8\times0{\cdot}6/1{\cdot}0\times21$, or 0·08 for the plastic compared with 1·0 for steel. Figures for other materials are shown in Table I.

LONG-TIME TENSILE : Plastics resemble many other materials in that long-time strength at room temperature is considerably lower than the tensile strength. This may be an important matter in design calculations. The long-time strength given is a stress that can be borne safely for two years, based on an extrapolation of creep data, Fig. 3. Creep curves for plastics at room temperature are somewhat similar to those of metals under low stress where a period of initial rapid creep is succeeded by a phase in which creep is almost linear with time. Many creep curves do not go beyond 1000 hours so that the creep rate given may be somewhat high.

At higher temperatures the creep curves for thermoplastics resemble those at room temperature except that the creep rate is much greater. But with thermosetting moulding materials and with laminates based on thermosetting resins the tendency to creep is offset by the tendency to shrink (arising from a loss of volatile matter). The actual creep curve resulting from the addition of these two effects at 192 deg. F. is somewhat irregular and the total elongation after 100 hours is generally less than that for a similar period and a similar stress at room temperatures. For this reason no creep rates are given at higher temperatures with respect to these materials.

With cellulose acetate the strength is usually limited by the deformation. It could probably sustain a stress of 1500 lb./sq. in. indefinitely but the strength given at room temperature is the stress at which the creep rate does not exceed 0·1 per cent per 1000 hours. There are insufficient data to allow a close estimate of the creep strength of polystyrene and polymethacrylate. It is fairly certain that a minimum figure of 1000 lb./sq. in. holds for both and that at this stress the creep rate is lower than 0·1 per cent per 1000 hours.

At room temperature the creep strength given for both steel and aluminium is the stress at the elastic limit and it is generally accepted that the creep at this stress is negligible for most calculations.

STRENGTH AT HIGHER TEMPERATURES : Creep strength is the stress than can probably be borne indefinitely (2 years) at the temperature cited. The tensile strength is the orthodox tensile strength after an exposure of 3 weeks for the laminates and thermosetting materials and a few hours for the thermoplastics. Some of the tensile data are converted from flexural data. In general these results at higher temperatures do not seem too consistent.

As indicated, the thermoplastics begin to display a loss in strength at 125 deg. F. With few exceptions they creep rapidly under a stress of 200 lb./sq. in. at 200 deg. F. The other plastic materials are more satisfactory in this respect and retain a considerable capacity to bear load at 192 deg. F. Above 300 deg. F. most common thermosetting materials and laminates cannot be used with reliance unless mineral is included in the formulation when the permissible temperature rises to 400 deg. F. or better.

WATER ABSORPTION : Most of the typical plastics listed in Table II absorb water to an extent which may be important when dimensional stability is to be maintained.

The figures presented are for either immersion in water or exposure to a saturated atmosphere for 21 days. The amount of water absorbed is about the same for either treatment. An exposure of this kind for 21 days has an effect that is far more severe than that caused by the sustained humidity of summer. The values for thermosetting materials and for laminates are for specimens $\frac{1}{8}$ inch thick. Those for thermoplastics are based on $\frac{1}{4}$ inch specimens. Thinner specimens tend to absorb water more rapidly and expand more freely.

Water absorption must be remembered particularly when a plastic product is to be exposed to water on one side only. Warping may occur in service because the wet side tends to expand on absorbing water while the dry side tends to retain its dimensions. Or, if warping is prevented, undesired stresses may arise that are large enough to cause failure. Where the typical materials offer too high a water absorption special formulations with lower absorptions are usually available.

COEFFICIENT OF THERMAL EXPANSION : Approximate values are given in the table and they apply only in the lower temperature ranges up to 125 deg. F. Above this, temperature expansion is often accompanied by shrinkage due to a loss of volatile matter, especially with the thermosetting materials, so that the coefficient becomes meaningless.

The high coefficient of expansion of plastics means that there must be forethought if they are to be used successfully in conjunction with metals in applications where the temperature is variable, as for instance in plastics bearings. Otherwise undersirable stresses or changes in dimension may occur. This is true also where plastic and metal are fabricated together at the moulding temperature for plastic and subsequent cooling allows the differing coefficients to express themselves.

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Dry Friction of Metals as Affected by Surface Finish and Surface Coatings

By N. LUDWIG. (From *Die Technik*, Vol. 2, No. 4, April, 1947, pp. 166-170, 4 illustrations.)

THE author has developed an apparatus to measure sliding friction, shown diagrammatically in Fig. 1. A unit pressure between 0·025 and 0·5 kg/sq. cm. is used to press a 1 cm. cube against a plane surface of 20 cm length which slides at a velocity between 0·1 and 10 cm/sec. The frictional force is measured by a calibrated spring mechanism within ± 2·3 per cent accuracy.

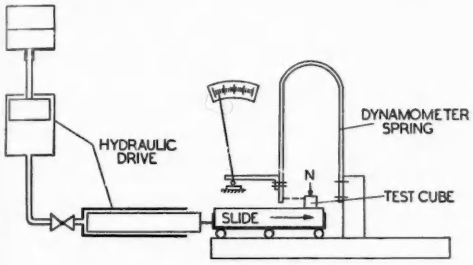

Fig. 1. **Test apparatus.** N = Load.

Preliminary tests have shown that :—When testing polished steel, cast iron, copper and brass surfaces under a pressure of 0·15 kg/sq. cm., variations in the sliding speed between 0·1 and 10 cm/sec. had no noticeable effect on friction. When the sliding velocity was maintained constant at 0·25 cm/sec., friction depended on pressure, as indicated in Fig. 2.

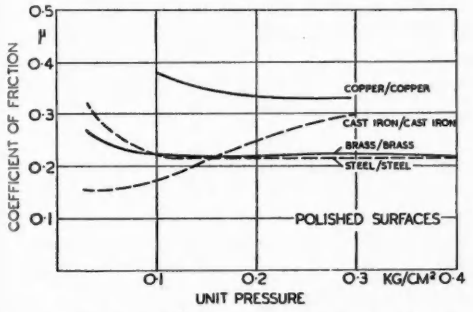

Fig. 2. **The effect of loading on the coefficient of friction.**

As a result of these experiments, a pressure of 0·15 kg/sq. cm. and a velocity of 0·25 cm/sec. were selected as the most suitable.

The effect of surface finish was examined for the following materials :—Thomas steel, type St 37.12 ; cast iron, type Ge 22.91 ; 99·9 per cent pure copper ; and brass containing 57 per cent Cu, 36 per cent Zn, 3 per cent Mn, 2 per cent Al and 2 per cent Fe. Four finishes were used :—Rough machined, fine machined, ground, and polished. The surface finishes were optically examined and found to be approximately, in decreasing order of roughness :

Steel : 100μ, 30μ, 10μ, and " completely plane " ;

Cast iron : 50μ, 25μ, 10μ, — (i.e., no figures being given for the polished surface);

Copper and brass: 35 — 40μ, 15μ, —, —.

TABLE I.—COEFFICIENTS OF DRY SLIDING FRICTION FOR DIFFERENT SURFACE FINISHES.

Pressure 0·15 kg/sq. cm., Velocity 0·25 cm/sec.

Materials	Coefficient of friction.		
	Fine-machined	Ground	Polished
Steel—steel ..	0·23	0·21	0·15
Steel—cast iron ..	0·24	0·22	0·17
Steel—copper ..	0·29	0·21	0·23
Steel—brass ..	0·18	0·17	0·16
Cast iron—cast iron ..	0·22	0·22	0·19
Cast iron—copper ..	0·33	0·27	0·21
Cast iron—brass ..	0·19	0·18	0·18
Copper—copper ..	0·31	0·29	0·29
Copper—brass ..	0·26	0·25	0·24
Brass—brass ..	0·18	0·22	0·19

TABLE II.—EXAMINATION OF PHOSPHATE COATINGS.

Coating	Temperature of bath, deg. C.	Approximate duration of treatment, min.	Thickness of layer approx. 1/1000 mm.
Parker	95–98	45	15
Bonder 2	90–98	5	10
Cold bonder ..	15–25	11	7
Ferrosphat ..	90–95	30	15
Immersion granodine	60–70	5	6
Granodine K ..	20–22	10	2
Adrament	98–100	45	15
Adrament C ..	90–95	8	3

144 individual readings were made with each pair of metals, using each material as the cube and the sliding surface, respectively. The coefficients of friction are given in Table I. The friction of the rough machined surfaces fluctuated considerably and therefore the figures are not included in the table. When moving against the direction of machining, frictional coefficients were higher on the average by 0·01 than when moving with the direction of machining, but this was usually within the range of scatter (0·02 — 0·15). The combinations with brass gave results practically independent of surface finish. No explanation is given for the rise in friction for brass against brass with a ground surface, as compared with fine-machined surfaces. With the other combinations (excepting steel—copper) friction tended to decrease as surface finish was improved. Among the fine-machined and ground surfaces the smallest coefficients of friction were observed for steel—brass and cast iron—brass. Friction was highest with combinations in which both metals contained copper. This may be related to the fact that microscopic particles of copper were observed on surfaces sliding under copper cubes.

TABLE III.—COEFFICIENTS OF DRY SLIDING FRICTION OF COATED SURFACES

Pressure 0·15 kg/sq. cm., Velocity 0·25 cm/sec

Coating	Coefficient of friction when sliding against				
	Identical surface	Uncoated steel		Cast iron	Al-Cu-Mg
		Ground	Fine-machined	Ground	
Parker	—	0·22	0·39	0·32	—
Bonder 2	0·48	0·18	0·44	0·36	—
Cold bonder ..	0·45	—	—	—	—
Ferrosphat ..	—	0·19	0·42	0·41	—
Immersion granodine	0·17	0·19	0·18	0·21	0·14
Granodine K ..	0·27	—	—	—	—
Adrament	0·28	0·17	0·31	0·25	—
Adrament C ..	0·27	0·19	0·40	0·25	0·19
Hard chromium plated	0·13	0·15	—	—	0·13*
Brass plated ..	0·17	—	—	—	0·16

*Sliding against immersion granodine coated surface.

The friction of various surface coatings was also determined. Details of the phosphate-coating methods used are given in Table II. They were applied to ground steel surfaces. The hard chromium plating was polished by hand. These surfaces were tested against ground and fine machined steel, ground aluminium and cast iron surfaces, and against similarly coated surfaces. The results of these tests are shown in Table III. Phosphate coating—with the exception of " parkerizing "—reduces the friction of ground steel, but increases the friction of fine-machined steel and cast iron surfaces. The hard chromium plated surface gave the lowest friction. Among the phosphate-coated surfaces, immersion-granodine gave the lowest friction.

SWITZERLAND

Investigation of the Principle of the Most Economic Voltage for Power Transmission over Long Distances

By W. FREY. (From *Brown Boveri Mitteilungen*, Vol. 33, No. 11, November, 1946, pp. 354-362, 8 illustrations.)

FOR the transmission of power over long distances, two types of problems have to be considered : (1) stability difficulties in a.c. power transmission, which have been investigated elsewhere and (2) the difficulties due to transmission of power without the use of supporting points, i.e. transformer stations along the line. It is not generally possible to maintain the power factor equal to unity, or to achieve conditions assuring that the line voltage is equal to the nominal voltage over the entire line length. The ideal state is only achievable when the power being transmitted is the *natural* power of the line for a given nominal voltage, and for any other power the ohmic line losses will be greater than in the ideal case with optimum current and voltage distribution.

The additional losses due to direct transmission without the use of supporting points are not prohibitive, as will be shown later on. They can be reduced by choosing the transmission voltage in such a way that the power most generally transmitted will be the natural power of the line. The corresponding voltage will then be the *natural voltage*. This method does not, however, cover all the aspects of the problem. For shorter line distance a different method can be applied : in this case the natural power of the line is not considered, but the transmission voltage is determined so that the total annual costs including line losses will be as low as possible. This same method can also be applied to the case of a long line without intermediate stations by first determining the power for which the annual costs of the line have a minimum value, and then estimating the additional costs due to the non-uniform current and voltage distribution. It might be objected that in practice there is only a choice between two or three standard voltages, but the present investigation is mainly a study of the principle involved and will primarily serve to determine the influence of the various parameters on the costs of the entire system.

1. THE LINE LOSSES AND THE OPTIMUM OPERATING CONDITIONS OF THE LINE.

The costs of power transmission can be divided into two parts : The first part represents the costs occurring as a result of a certain proportion of the energy fed into the line being converted into heat ; these costs will be called the *line loss costs*. The second component of the total costs consists of the annual expenditures for the line and the terminal stations ; these are the *capital costs* of the transmission.

The costs of the line losses can be calculated as a function of the power being transmitted. Let P = total energy transmitted (kW) ; U_n = nominal voltage (kV) ; p = number of parallel conductors used ; l = line length ; γ = correction factor ; ρ = specific resistance of conductor material (ohm mm²/metre) ; q = conductor cross-section (mm²) ; P_v = losses in all conductors ; P_{vo} = losses in all conductors if the voltage were everywhere equal to the nominal voltage and the power factor were equal to unity over the entire line. The " ideal losses " are then given by :

$$P_{vo} = \frac{P^2}{pU_n^2} \frac{\rho l}{q} \quad .. \quad .. \quad (1)$$

and the real losses are

$$P_v = \gamma P_{vo} \quad .. \quad .. \quad .. \quad (2)$$

where γ is the correction factor. The factor γ can be determined with the aid of the following consideration. In high-voltage installations the ohmic voltage drop is small relative to the inductive drop. The ohmic line losses can thus easily be calculated from the equations for the loss-free line. If I_x is then the value of the current at a point x along the line, then the losses between the points $x = a$ and $x = b$ on the line are given by

$$P_v = 3p \frac{\rho}{q} \int_a^b I_x^2 \, dx \quad .. \quad .. \quad (3)$$

This calculation avoids the tedious computation by means of hyperbolic functions with a complex variable.

In general the operating conditions of the line are not fully determined when only the nominal voltage and the transmitted power are known. It will therefore be assumed that the nominal voltage is not exceeded at any point along the line, and to determine conditions still further, we will choose in each case the operating condition which gives the lowest ohmic losses. This will be called the *optimum operating condition* ; and it will be necessary in this connection to distinguish two cases :—

1. If the power transmitted is less than the natural power of the line at nominal voltage, then the line must be regulated in such a way that the nominal voltage of the line is reached at the centre of the line, with lower voltage values at the two ends.
2. If the power transmitted is greater than the natural power, then the line must be regulated so that its ends will be at the nominal voltage, with the voltage at the centre lower than the nominal voltage.

In order to calculate the voltage variations from the nominal voltage under the optimum operating conditions, the following symbols will be introduced : P_N = = natural power of the line at nominal voltage ; $\eta = P/P_N$ = transmission efficiency ; $\mathbf{U}_m$ = voltage at centre of line ; $\mathbf{U}_1$ = voltage at ends of line ; $\xi = U_m/U_n$ ($\xi = 1$ for $\eta < 1$) ; $\zeta = U_1/U_n$ ($\zeta = 1$ for

$\eta > 1$) ; Z = wave resistance. It can be shown that under optimum conditions the current and phase-voltage are in phase at the centre of the line, and that the current distribution is symmetrical relatively to the centre of the line so that it will only be necessary to consider one half of the line. The current at the centre of the line (point $x = 0$) is then

$$I_m = (\eta\, U_n)/(\sqrt{3}\,\xi Z) \quad .. \quad .. \quad (4)$$

and at any point x along the line, the current and voltage are :

$$\left.\begin{aligned} \mathbf{U}_x &= (\xi \cos x + \mathrm{j}\,\frac{\eta}{\xi} \sin x)\,\mathbf{U}_n, \\ \mathbf{I}_x &= (\xi\, j \sin x + \frac{\eta}{\xi} \cos x)\,\frac{\mathbf{U}_n}{Z}. \end{aligned}\right\} \quad .. \quad (5)$$

If Φ is the length of the line (expressed in radians) :

$$\Phi = \frac{2\pi f \,.\, l}{300{,}000} \quad \text{(where } f = \text{frequency)},$$

then by substituting $x = \pm \Phi/2$ in eqn. (5), we obtain the values of the current and voltage at the line's ends. For $\eta < 1$, $\xi = 1$. For $\eta > 1$ it will be necessary to calculate ξ as a function of η. For this we can put $x = \Phi/2$ in one of the equations (5) ; then $\mathbf{U}_x$ will be equal to $\mathbf{U}_1$. But in this case $U_1 = U_n$. This gives thus an expression for determining ξ :

$$\xi^2 = 2 \sin^2 \frac{\Phi}{2} \,.\, \frac{1 + \sqrt{1 - \eta^2 \sin^2 \Phi}}{\sin^2 \Phi} \quad .. \quad (6)$$

For $\eta < 1$, ζ can be determined just as simply :

$$\zeta = \sqrt{1 - (1 - \eta^2) \sin^2 \frac{\Phi}{2}} \quad .. \quad (7)$$

Eqns. (6) and (7) give the variations from nominal voltage as functions of the relative load η under optimum operating conditions, and the corresponding curves are shown in Fig. 1. It will be seen that generally the variations are relatively slight. (It should be noted that in these equations the voltages must always be regarded as phase voltages, while the present calculation is only concerned with linkage voltages.) Final conclusions cannot yet be obtained, as we do not yet know the voltage at which the line will work under most economical conditions. Furthermore, the curves have not been continued for η values exceeding certain limits, because under the assumptions made, there exists a maximum transmissible power for each line length. At 1,500 km no power exceeding the natural power can be transmitted.

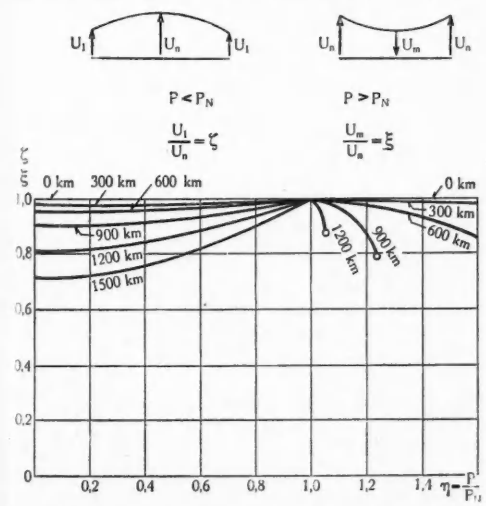

Fig. 1. **Variations of voltage at the end and at the centre of the line from the natural voltage.**

P_N = natural power ; P = transmitted power ; U_n = nominal voltage.

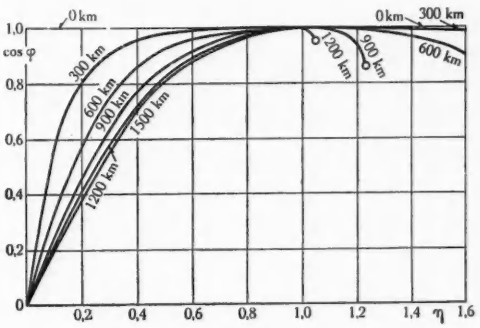

Fig. 2. **Power factor at the two ends of the line.**

The power factor at the end of the line can now be calculated with the aid of equations (5), (6) and (7), and the resulting relationships are given graphically in Fig. 2. The correction factor γ still has to be calculated. On the real line the losses are proportional to

$$\int_0^{\Phi/2} I_x^2 \, dx,$$

and in the ideal case they vary as

$$\left(\eta \frac{U_n}{Z}\right)^2 \cdot \frac{\Phi}{2},$$

therefore γ is determined by

$$\gamma = \frac{\int_0^{\Phi/2} I_x^2 \, dx}{\left(\eta \dfrac{U_n}{Z}\right)^2 \dfrac{\Phi}{2}} \quad .. \quad (8)$$

I_x^2 can be calculated from (5) and substituted in (8), thus giving

$$\gamma = \frac{1}{2}\left[\frac{1}{\xi^2} + \frac{\xi^2}{\eta^2} + \left(\frac{1}{\xi^2} + \frac{\xi^2}{\eta^2}\right)\frac{\sin \Phi}{\Phi}\right] \quad (9)$$

Substituting for ξ and ζ according to equations (6) and (7) we find for the two cases $\eta \lessgtr 1$:

$$\eta < 1 : \gamma_< = 1 + \frac{1}{2}\left(\frac{1}{\eta^2} - 1\right)\left(1 - \frac{\sin \Phi}{\Phi}\right) \quad (10)$$

$$\eta > 1 : \gamma_> = \frac{1}{\eta^2}\left(\frac{\Phi + \sin \Phi \cos \Phi}{\Phi \sin^2 \Phi} - \frac{\Phi \cos \Phi + \sin \Phi}{\Phi \sin^2 \Phi}\sqrt{1 - \eta^2 \sin^2 \Phi}\right)$$

For a graphical representation the two quantities

$$\nu_1 = \gamma - 1 \text{ and } \nu_2 = \eta^2(\gamma - 1) \quad .. \quad (11)$$

have been used. ν_1 represents the additional losses relative to the ideal losses ; as these are equal to zero under no-load conditions, we have $\nu_1 = \infty$ for $\eta = 0$. ν_2 represents the losses relative to the losses occurring in transmitting the natural power, and gives therefore an idea of their variation. It will be seen from Figs. 3 and 4 that the additional losses are slight for small variations from the natural power.

2. The Capital Costs of the Lines.

When in the project of a line the number of parallel conductors and the basic design of the line are known, then the erection costs per unit length will depend chiefly on the nominal voltage and on the cross-section of the conductors. Various attempts have been made to express these costs depending on two parameters only by means of formulæ. The assumption is that the costs of the line can be divided into three parts : (1) a fixed cost portion, depending only on the type of line and not on the conductor cross-section or voltage ; (2) a part depending on the conductor cross-section only ; and (3) a part depending on voltage only. Assuming a linear law for our calculations, we can then write for the construction costs K_b :

$$K_b = F + gU_n + qs \quad .. \quad .. \quad (12)$$

where K_b = construction costs (Swiss Frs. per km.); F = fixed cost portion (Sw. Frs./km.) ; U_n = nominal voltage (kV) ; q = conductor cross-section (mm²) ; g = constant (Sw. Frs./km. kV) ; s = constant (Sw. Frs./km. mm²). This investigation will only deal with high-voltage lines, using hollow conductors, and is based on an article by Voegeli* on the costs of overhead lines. The conductor diameter is then to a great extent independent of the conductor cross-section, and is mainly determined by the permissible value for the corona losses of the line. The conductor diameter increases, however, with the operating voltage* according to the formula :

$$d = 0{\cdot}12\, U_n \quad .. \quad .. \quad .. \quad (13)$$

where d is the conductor diameter in mm. The cross-section will then only affect the wall thickness of the conductors. The part of the constructional costs which depends on the cross-section includes not only the costs of the conductors but also a factor for the supports since these are more expensive for heavier conductors. On the basis of the data given by Voegeli and taking account of (13) the following values can be employed :

	F Frs./km.	g Fr./km. kV.	s Fr./km. mm²
1-wire copper line ..	$11{\cdot}5 \times 10^3$	102	62·5
2-wire copper line ..	$22{\cdot}5 \times 10^3$	158	120

It has been estimated that of the costs qs depending on the cross-section approximately 50 per cent can be ascribed to the conductors proper and their supporting structures.

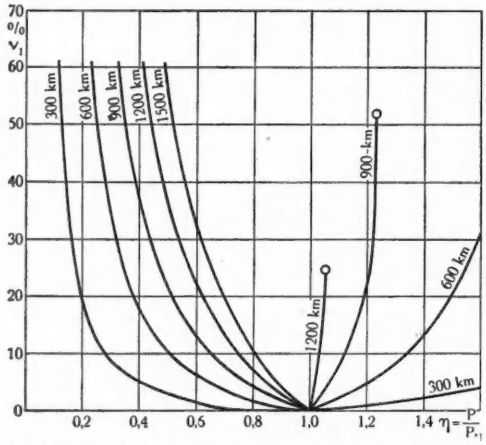

Fig. 3. **Additional losses due to the variation of transmitted power from the natural power.**

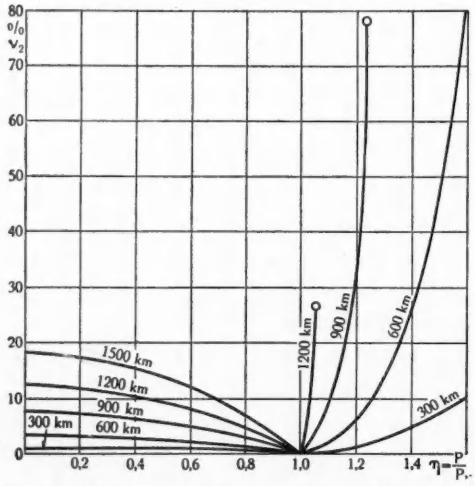

Fig. 4. **Additional losses due to variation of transmitted power from the natural power.**

3. The Total Annual Costs of the Energy Transmission.

For simplicity it will be assumed that the line is operating with a constant power P during $\lambda \times 8760$ hours per annum (8760 hrs. = 1 year, $\lambda \leq 1$). The price of energy will be represented by the price v (Sw. Frs.) of one kilowatt-year (= 8760 kWh.). Furthermore, a fixed fraction zK_b has to be spent annually for amortization, operation and maintenance of the line. The annual costs for energy transport per kilometre are then given by :

$$k = z\,(F + gU_n + sq) + \lambda\, v\, \frac{P^2}{pU_n^2}\, \frac{\rho\, l}{q}\, \gamma(\eta) \quad (14)$$

Instead of the nominal voltage U_n, it will be more convenient to use the natural voltage U_N corresponding to the power P. Then

$$U_n = \mu\, U_N \quad .. \quad .. \quad (15)$$

where μ is a proportionality factor, and

$$U_N = \frac{1}{\sqrt{p}} \sqrt{PZ}\, \sqrt{10^{-3}} \quad .. \quad (16)$$

Furthermore it will easily be seen that

$$\eta = \frac{1}{\mu^2} \quad .. \quad .. \quad (17)$$

If we regard the transmitted power P and the wave resistance Z which is practically independent of the

*Voegeli, R. : The overhead line and its costs. *Brown Boveri Mitt.*, Nov., 1941.

voltage as given, then the dimensionless quantity μ will appear as an independent variable in the calculation. Moreover, as a result of eqn. (17), γ will also be a function of μ. Substituting μ in eqn. (14) and using the following abbreviations :

$$D = \sqrt{PZ}\sqrt{10^{-3}}\,\frac{g}{\sqrt{p}},\quad C = P\rho v\lambda 10^{3}/Z \qquad (18)$$

we obtain :

$$k = z(F + D\eta + sq) + C\gamma(\mu)/(q\mu^{2}) \qquad (19)$$

where q and μ are the only independent variables.

4. The Most Economic Power without taking Account of the Influence of the Terminal Stations.

The simplified method will first be developed, without taking into account the influence of the costs of the two terminal stations, which vary considerably with voltage. The optimum values of the two quantities q and μ, which correspond to minimum costs, can be obtained by equating to zero the two partial derivatives of k with respect to q and to μ :

$$\frac{\partial k}{\partial q} = zs - \frac{C}{q^{2}\mu^{2}}\gamma(\mu) = 0 \qquad (20)$$

$$\frac{\partial k}{\partial q} = zD - 2\frac{C}{q\mu^{3}}\gamma(\mu) + \frac{C}{q^{2}\mu^{2}}\gamma'(\mu) \qquad (21)$$

which give

$$\left(\frac{D^{2}z^{2}}{4CsZ}\right)^{\frac{1}{4}} = \left[\frac{\gamma - \frac{\mu\gamma'}{2}}{\sqrt{\gamma}}\right]^{\frac{1}{4}} \qquad (22)$$

and with the abbreviations

$$Q = \left(\frac{D^{2}z^{2}}{4Csz}\right)^{\frac{1}{4}} = \left(\frac{Zgz}{2000}\right)^{\frac{1}{4}} = (\rho s\lambda v p z)^{-\frac{1}{4}} \qquad (23)$$

$$\Gamma(\mu) = \sqrt{\frac{\gamma - \frac{\mu}{2}\gamma'}{\sqrt{\gamma}}} \qquad (24)$$

we obtain

$$Q\mu = \Gamma(\mu) \qquad (25)$$

From eqn. (25) the value of μ for minimum costs can be calculated and then, with eqn. (15) and (16), the most economical voltage can be determined. The values of μ and of $\Gamma(\mu)$ which also depends on the line length, can best be determined graphically (see Fig. 5, where $\Gamma(\mu)$ is plotted against μ for various line lengths). The curves have a discontinuity at the point $\mu = 1$ as beyond this point γ and hence Γ is represented by a different analytical expression ; this is so because the operating conditions are different depending on the power being greater or less than the natural power of the line. Furthermore, the straight line $Q\mu$ is also given in the diagram, and its intersection with the corresponding curve gives the required value of μ.

From Fig. 5 it will be seen that for a fixed value of Q, i.e. for given cost constants, etc., μ tends towards unity when the length of the line increases. When Q is smaller than unity, $\mu \geq 1$. In this case μ decreases with increasing line lengths, and the optimum voltage will decrease correspondingly. The reason for this result is that if the various cost constants are constituted in such a way that Q becomes less than unity, then the most economic voltage for short line lengths will be so high that for this voltage the full natural power cannot be transmitted, whilst with longer lines the additional

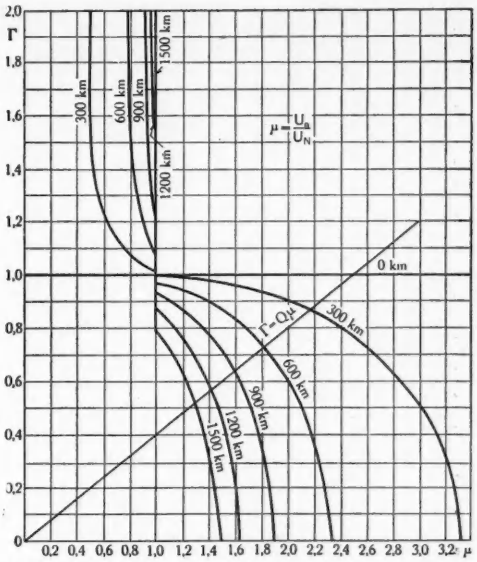

Fig. 5. Family of curves for the determination of the most economical voltage U_n.

costs will become apparent. Thus the economic voltage will be at a lower value, nearer to the natural voltage. When Q is greater than unity, the reverse conditions prevail.

From eqn. (23) it follows that Q will be greater when the portion of the costs g depending on voltage increases relatively to the costs s depending on the cross-section. A large Q corresponds to a small μ and therefore to a lower voltage. Furthermore Q will be greater the cheaper the energy is (smaller v) and the less the line is in operation during the year (smaller λ). With cheap current and a short operating period less capital will have to be put into the construction of the line than with a more expensive current and a longer operating period.

5. The Most Economic Voltage when the Stations' Costs are also Considered.

It will be assumed in this generalized theory that the stations' costs are a function of the dimensionless variable μ :

$$K_{s} = \sigma(\mu) \qquad (26)$$

For the stations the same factor z for the amortization, etc., will be assumed as previously. Then the annual costs of the two terminal stations per kilometre of line length will be

$$k_{s} = 2z\sigma(\mu)/l \qquad (27)$$

and this expression should be added to the terms of equation (19). Thus $D\mu$ has to be replaced by $D\mu + 2\sigma(\mu)/l$. In the further calculation only the derivative of the term depending solely on μ occurs. Therefore D will have to be replaced by

$$D_{s} = D\left[1 + \frac{2}{lD}\sigma'(\mu)\right] \qquad (28)$$

With this value a new coefficient Q_{1} can be determined and this leads to an equation for determining μ similar to equation (25) :

$$\mu Q_{1} = \mu\sqrt{1 + \frac{2}{lD}\sigma'(\mu)}\;Q = \Gamma(\mu) \qquad (29)$$

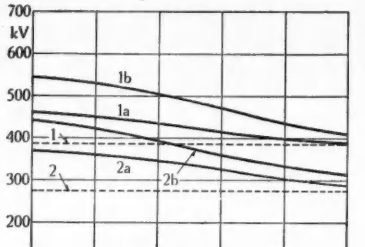

Fig. 6. **Most economic voltage without taking account of the station costs.**

Power transmitted = 400,000 kW. Wave resistance = 375 MW. Curves 1 : single wire line with hollow copper conductors. Curves 2 : double wire line with hollow copper conductors. Curves a : ratio of price of energy to relative utilization period = 0·007 Sw. Fr./kWh. Curves b : same ratio = 0·014 Fr./kWh. Dotted lines = natural voltage U_N.

Q_s is now no longer independent of μ and μQ_s is no longer a straight line. Instead of plotting the new curve μQ_s it will be more convenient to proceed as follows : A value μ_1 is first estimated and with this Q_{s1} is determined from eqn. (29). A new value μ_2 is then calculated, as if Q_{s1} were independent of μ. The process is repeated with μ_2, etc. After a few trials the μ value at the end of one trial will hardly vary from the value previously obtained, and as soon as this is found to be the case, the μ value thus determined will be a solution of eqn. (29).

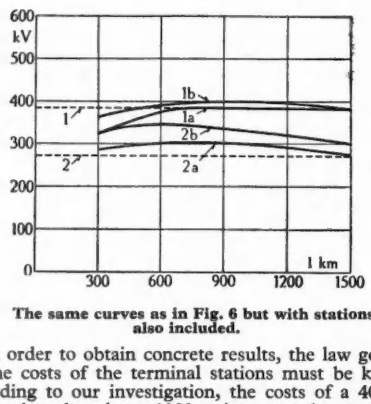

Fig. 7. **The same curves as in Fig. 6 but with stations' costs also included.**

In order to obtain concrete results, the law governing the costs of the terminal stations must be known. According to our investigation, the costs of a 400,000 kW station, based on 1939 prices, can be expressed by $K_s = 6{\cdot}2 \times 10^6 + 0{\cdot}0612 \, . \, U_n^3$ Swiss Frs. With this assumption, the function $\sigma(\mu)$ of eqn. (26) and its derivative $\sigma'(\mu)$ can easily be determined, and the results of the corresponding calculation for the most economical voltage are shown in Fig. 7. The curves, unlike those of Fig. 6, show that for short line lengths the most economic voltage increases with the line length, and then decreases after having reached a maximum value ; hence for short line lengths the station costs will cause a considerable decrease of the economic voltage. This is because, for short line lengths, the station costs depending considerably on the voltage are a large portion of the total costs ; with increasing line lengths this influence decreases steadily and the most economic voltage will rise at first until the additional losses of the line prevent any further increase or even lead to a decrease of the most economic voltage. It is worth noting that for transmission with a single-wire line over short distances the most economic voltage is lower than the natural voltage.

It is also a remarkable fact that the theoretically most economical voltage does not vary too much from the natural voltage for short line lengths. This means that only a slight adjustment of voltage will be required on account of the additional losses ; whereas if there had been a greater variation between the two values, the economic voltage would decrease extremely rapidly with increasing line lengths.

The total costs of energy transmission per kilometre and per year, calculated for a line length of 1200 km., are given in Table I. The price of energy is based on ideal losses only and assumes that the line is designed for most economical operating conditions. The extra costs due to additional losses are expressed as a percentage.

TABLE I.—TRANSMISSION COSTS PER KILOMETRE AND PER YEAR (INCLUDING STATION COSTS).

Number of wires.	Price of energy relative to period of utilization Sw. Fr./kWh.	Costs (ideal losses). Fr./km. year.	Additional costs due to additional losses %	Curve in Fig. 7.
1	0·007	14,000	1·4	1a
1	0·014	16,700	4·3	1b
2	0·007	11,100	0	2a
2	0·014	13,700	1·0	2b

The table shows that the additional costs are extremely low (see also Fig. 7). The curve in Fig. 8 gives the annual costs of a double-wire line as a function of the wave resistance, for a line length of 1,200 km., assuming the wave resistance can be varied without altering the costs constants of the line. The curve has a minimum at 560 ohms, for which, when $\mu = 1$, the factor Q_s is exactly equal to unity. For this particular value the costs are the same as those of an ideal line with no additional losses. The curve shows that the wave resistance has just the right order of magnitude required for the given conditions. Therefore a smaller wave resistance does not necessarily mean improved economic conditions.

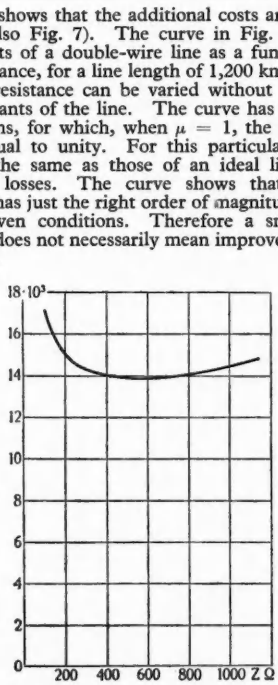

Fig. 8. **Influence of wave resistance on transmission costs.** Transmission of 400 MW over 1200 km. with double line of copper conductors. Ratio of the price of energy to relative utilization period = 0·007 Sw. Fr./kWh.

For the powers under consideration (see Figs. 1 and 2) neither the voltage variations nor the power factor at the ends of the line will assume values which could be detrimental to an economic operation of the line. Therefore, it can be said that the operation of a line without supporting points, i.e. without intermediate stations, does not involve any disadvantages from the purely economical standpoint.

Experimental Steel Production with Oxygen-enriched Blast in Bessemer Converter at Kuznetsk Steel Works

By V. V. KONJAKOV. (From *Kislorod*, Vol. 3, No. 2/3, 1946, pp. 1-11, 20 illustrations.)

IN 1945 a special converter plant was established at the Kuznetsk Steel Works in order to study the production of Bessemer steel with the employment of oxygen-enriched or pure oxygen blast. Fig. 1 shows the bottom-blown converter employed. There are one central tuyere and 8 concentrically arranged identical tuyeres, the distance between the latter and the wall of the converter well being 225 mm. (8⅞ in.). The diameter of the tuyeres is given as 12-14 mm. ($\frac{1}{2}\frac{2}{3}$-$\frac{9}{16}$ in.).

The walls and the bottom of the converter are lined with bricks. The cubical content of the converter is 1·25 cu. m. (44 cu. ft.) and its normal capacity is 1,500 kg. (3,307 lb.) the specific converter volume therefore is 1·52/1·50 = 1 cu. m. (35·3 cu. ft.) per ton. This ratio approximates to that employed in ordinary air-blown converter practice.

The various tests made were carried out with the charge ranging from 1·4 to 1·8 tons, and the metal volume varied correspondingly between 0·2 and 0·26 cu. m. ; while the ratio of converter volume to metal volume ranged from 7·6 to 5·9. The cross-sectional area of the converter well was 0·56 sq. m. (6 sq. ft.), and the height of the liquid metal in undisturbed state ranged from 0·36 to 0·465 m., which closely agrees with American practice. The individual tuyere area, was 1·54 sq. cm., resulting in a total tuyere area of 9 × 1·54 = 13·8 sq. cm. (2·14 sq. in.). The tuyere area per ton of charge therefore ranged from 9·97 to 7·68 sq. cm. per ton, which compares with some 10 sq. cm. per ton for air-blown bessemer converters. An elevation of the converter is given in Fig. 2.

The tests were carried out with blasts containing 100 per cent, 75 per cent and 50 per cent oxygen respectively. The metal charge was taken from a cupola of 4 tons per hour capacity. The oxygen was supplied from the central oxygen plant of the works through a pipe line at 10 atm. (142 lb./sq. in.) pressure. Both the oxygen and the air blast were regulated by a manually controlled valve. Orifices were provided for measuring the respective flow rates of air and oxygen. The blast pressure was automatically controlled ; as was also the oxygen/air ratio. The temperature of the converter lining was measured by means of appropriately installed thermocouples. Metal, slag and flame temperatures during blowing were measured with an optical pyrometer.

Theoretical computations had shown that the silicon and phosphorus contents of the metal can be reduced to zero by blowing with pure oxygen. The heat released by the combustion of the carbon content of the metal is sufficient to raise the temperature of the charge to 1,500 deg. C. and higher. Of the 15 heats blown, 11 were blown with technically pure oxygen, 2 were blown with 25 per cent air and 75 per cent oxygen, and 2 were blown with 50 per cent oxygen and 50 per cent air.

The first run with oxygen blast showed that the refractory tuyeres must be replaced after every single heat. Towards the end of the blow, some 10 kg. ferromanganese were added. After 3 to 5 minutes the metal was

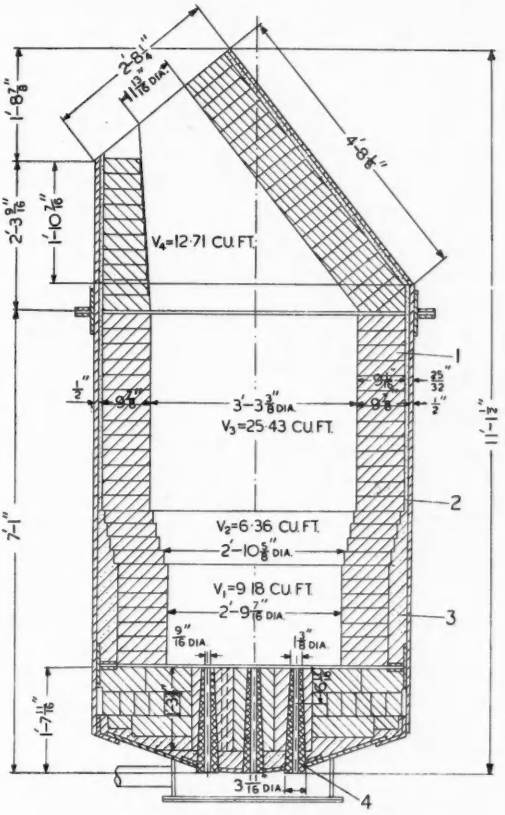

Fig. 1. Lining of 1·5 ton converter.

(1) Brickwork ; (2) Asbestos packing ; (3) Firebrick rubble ; (4) Lower part of tuyere (fire brick) ; (5) Upper part of tuyere (special refractory).

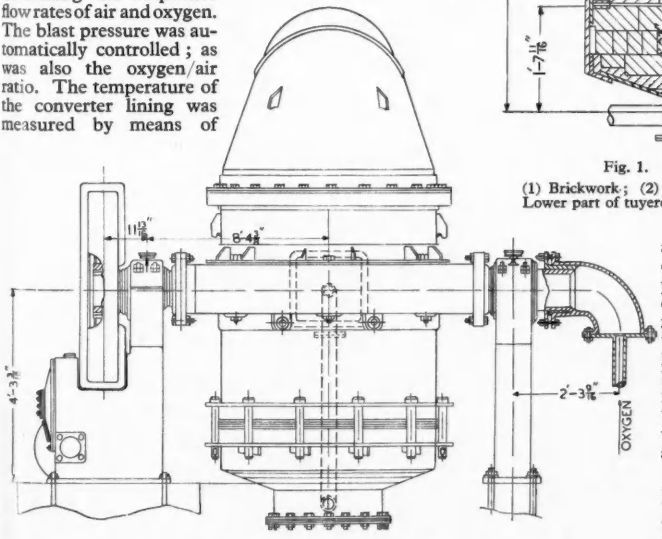

Fig. 2. Converter of 1·5 ton capacity for working with oxygen blast.

No. of heat.	Length of blow.		Weight of charge, kg.	Final weight, kg.			Metal output %	Oxygen in blast %	Total consumption of oxygen, cu. m.		Total consumption of oxygen for blowing with oxygen enriched air, cu.m./ton.
				Steel	Slag	Blowing loss.			per heat.	per ton of metal.	
	min.	sec.									
1	4	30	Not weighed.					100	68·4	41·0	—
2	4	32	1720	1297	80	Not determined.	75·6	100	71·1	41·3	—
3	5	04	1625	1302	65	120	80·2	100	66·5	36·5	—
4	4	55	1590	1187	90	201	75·0	100	62·4	39·2	—
5	4	50	1800	1346	56	390	75·0	100	71·3	39·6	—
6	4	24	1600	1395	53	83	87·2	100	53·4	33·4	—
9	7	05	1700	1565	35	nil.	92·0	100	78·2	46·0	—
10	6	48	1750	1543	63	nil.	88·2	100	78·1	44·7	—
11	11	25	1630	1535	65	unknown	94·1	73	80·1	46·6	56·5
12	11	06	1720	1557	95	unknown	90·8	75	77·0	45·2	52·3
13	13	09	1700	1530	110	unknown	90·0	50	62·0	36·5	45·2
14	13	10	1780	1705	50	nil.	95·8	50	60·0	35·7	45·2
15	7	33	1480	1398	46	nil.	94·5	100	79·4	53·6	—

poured into a ladle, and 5 kg. ferromanganese, 5 kg. ferrosilicon and 0·7-1·0 kg. aluminium were added. The metal temperature was measured by pyrometer during pouring and was found to range from 1,460 to 1,500 deg. C. Whenever the temperature of the metal in the ladle was above 1,500 deg. C., the metal was allowed to cool to 1,450-1,460 deg. C. before casting the ingot of 1,350 kg. in an ingot mould of special steel.

Quantitative data is given in the above table, in which the blowing times and the composition of the blast are also listed. The amount of nitrogen contained in the technically pure oxygen varied from 0·5 to 2·5 per cent. The blast pressures ranged from 1·0 to 1·4 atmospheres and were manually adjusted during blowing. When blowing pure oxygen, the blowing time was from 4 to 5 minutes in most of the heats ; but when using tuyeres of 10 mm. dia. (instead of 14 mm.), the blowing time had to be increased to 7-7·5 minutes. Upon introduction of the charge into the converter, the blast was turned on, and when the blast pressure had reached 0·8 atm., the converter was brought into the vertical position, and the blast pressure was then increased to 1·1-1·2 atmospheres.

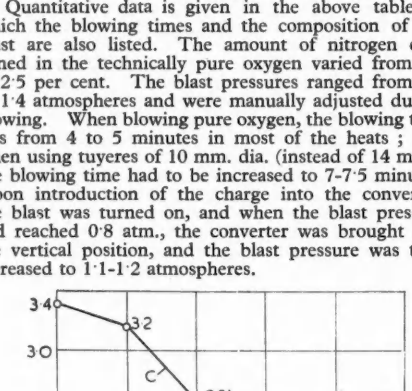

Fig. 3. **Chemical blowing loss. (Heat No. 6.)**

In order to determine the chemical losses in silicon, manganese, and carbon, a special test was made in which samples of the metal were taken every minute. The losses ascertained in this way at various stages of the blow are charted in Fig. 3 which refers to a blow of 4·5 minutes duration. Corresponding data for a blow of 7 minutes is given in Fig. 4.

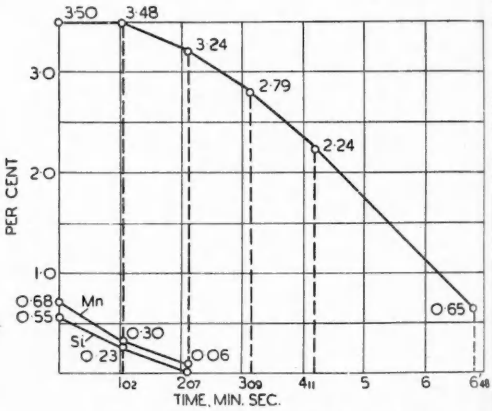

Fig. 4. **Chemical blowing loss. (Heat No. 10).**

An outstanding advantage of the oxygen-blown Bessemer steel was found to be its very low nitrogen (and hydrogen) contents ; typical figures are given below.

Heat No.	Oxygen content of blast, %	Nitrogen content of steel, %
2	100	0·0021
3	100	0·0010
4	100	0·0013
9	100	0·0022
12	75	0·0038
14	50	0·0059

These figures compare with a nitrogen content of 0·003-0·004 per cent for electric furnace steel, of 0·004-0·006 per cent for open hearth steel, and of 0·012-0·015 per cent for ordinary Bessemer steel.

The following conclusions were drawn by the author.

Oxygen blast can be applied to metal with low silicon content. Further progress towards a reduction in phosphorus percentage is, however, necessary.

The steel obtained exhibits increased mechanical strength and has a very low nitrogen content. The macro- and micro-structures of rolled specimens are satisfactory.

Under normal operating conditions the blowing loss is not larger than with normal air blast ; in fact it is sometimes rather less. Oxygen consumption approximates to theoretical requirements and amounts to some 40 cu. m. per ton of charge.

Further development of the process must be directed towards a longer service life of the tuyeres, and a suitable method for automatic control of the process must also be found.

Research into the Laws of Heat Dissipation in Journal Bearings

By CH. HANOCQ. (From *Revue Universelle Des Mines*, Vol. 3, No. 7, 1947, pp. 245-258, 32 illustrations.)

KNOWLEDGE of the physical laws relating to heat dissipation from transmission bearings is as important as a knowledge of the coefficient of friction, yet no systematic research has hitherto been undertaken. The purely empirical formulæ used, at present, for the design and dimensioning of bearings do not correspond to physical reality. They are only valid within the limits of the experimental circumstances from which they were derived, and generalized deductions are apt to be misleading. The following tests lead to new, and more accurate, formulæ having a strictly physical background and meaning.

TESTS AND TEST RESULTS.

A test bearing was arranged inside an insulated chamber (Fig. 1) and loaded by a dynamometer acting,

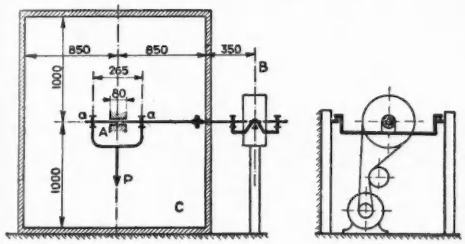

Fig. 1.

via a lever and bell crank, on two ball bearings at either side of the test bearing. The test temperature of the air in the chamber could be kept constant within ± 1·5 deg. C. and was chosen to be between 25 and 50 deg. C., with most tests being run at 28 deg. C. (82·5 deg. F.). The transmission shaft was driven from outside the chamber to avoid air disturbance inside. Conditions for heat exchange with the ambient air were thus as unfavourable as possible and a minimum value of the coefficient of heat transmission would therefore result. Direct measurement of the friction couple would lead only to an apparent coefficient of friction f_e different from the true coefficient f which was measured from the slowing down of a free running flywheel which was arranged outside the chamber on hinged bearings so that no additional reaction could reach the test bearing. One or two friction tests were taken after each test run. During these runs the air temperature was kept strictly constant and the oil bath temperature was measured at 15 minute intervals and plotted against time until, after four to five hours, the resulting curve was practically horizontal and the oil temperature was stable. When such equilibrium is reached, the heat generated by friction is equal to the heat dissipated.

Different types of test bearings were arranged in the following groups :—

GROUP I. Two short rigid bearings with bronze bushes and a central oilring fixed to the shaft. Diameter of shaft 40 and 60 mm. ($1\frac{9}{16}$ and $2\frac{3}{8}$ in.). See Fig. 2.

GROUP II. One specially designed bearing with a limited degree of self-alignment, with zamak bushes, and an oilring fixed to shaft on one side of the bush, 40 mm. dia. See Fig. 3.

GROUP III. One specially designed rigid bearing with a bronze bush, with an oilring fixed to shaft on one side of bush and length equal to the diameter of 40 mm. Fig. 4.

GROUP IV. Two very long self-aligning bearings with white metal bushes, central oilring fixed to 40 mm. dia. shaft and external swivel pivot. The two bearings differ in amount of play only. See Fig. 5.

GROUP V. Two very long bearings with white metal bushes, floating oilrings and internal swivel pivot. 40 and 60 mm. shaft diameters. See Fig. 6.

GROUP VI. Two bearings, one as group IV, one as group V, 40 mm. diameter, bearing surfaces reduced to half by counter-boring bearing ends.

Earlier tests by the same author* had led to the equation :

$$p f V = k (t_r - t_a) + k' (t_r - t_a)^4 \text{ cm.kg./cm}^2 \text{ sec.} \quad (1)$$

where p = kg. load per cm² projected bearing surface, f = the true coefficient of friction, V = rubbing speed in cm/sec., t_r = oil bath temperature, t_a = ambient air temperature, both in deg. C., and

$$k = 0{\cdot}33, \; k' = 4{\cdot}10^{-6}.$$

Eqn. (1), however, does not take account of the influence of the outer bearing surfaces, and the test results now given by Figs. 2, 3, 4, 5 and 6 show that k and k' are not constant but vary from group to group as well as within the groups. Equating, more strictly, the total heat generated to the total heat dissipated, we obtain :—

$$Apf SV = Ak_0 S' (t_r - t_a) + Ak_0' S' (t_r - t_a)^4 \quad .. \quad (2)$$

and

$$pf V = k_0 (S'/S) (t_r - t_a) + k_0' (S'/S) (t_r - t_a)^4 \quad (3)$$

where A = the projected bearing surface, S = the total bearing surface, S' = the total outer surface of bearing block except for that part of the bottom face which is covered by the bearing support. k_0 and k_0' now lead to certain constant values irrespective of type and size of bearing, and general test results relating to the value of k_0 are :—

(1) k_0 increases with increasing diameter in groups I and V ;

(2) k_0 is much smaller for group V than for group I. The long bushings of group V have less metallic contact with the housing and heat transmission is therefore smaller.

(3) k_0 is larger for group IV than for V. The fixed oilring of group IV provides a more active oil circulation and the better metallic connexion between bush and housing favours heat transmission not only by oil convection but also by metallic conduction.

(4) Bearings in groups II and III show very high k_0 values because their bushes are short and metallic connexion with housings is ample.

(5) Within expected experimental errors, the shortened bearings of group VI show no improvement over their respective originals of groups IV and V. This important result indicates that k_0 does not change with bearing surface S and that the influence of the outside surface S' is decisive.

INFLUENCE OF BEARING METAL, SELF-ALIGNMENT, AND FILM LUBRICATION.

Fig. 7 shows the measured friction values from which the diagram Fig. 2 was drawn. Points 1, 2, 6 and 9 of Figs. 7 and 2 stand out and are clearly due to imperfect lubrication and metallic contact. All the other points are grouped characteristically about the theoretical friction curve, which is drawn in Fig. 7. In fact, if the straying values of these points are replaced by the corresponding theoretical friction values the curve of Fig. 2 still remains correct in shape but the stray field of the experimental points is narrowed considerably.

* *Rev. Univ. des Mines*, August 1, Sept. 1 and 15, 1929.

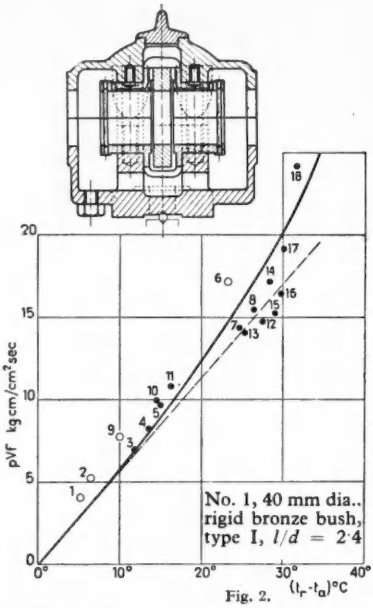

Fig. 2.

These findings were confirmed by further tests when the bronze bush of bearing Fig. 2 was replaced by a zamak bush of identical size. Fig. 8 summarizes the results of the tests. The values for imperfect lubrication are separated in curves B and Z, and the values for hydro-dynamic film lubrication, with theoretically correct friction coefficients, are given by curves B_n and Z_n for bronze and zamak bushes respectively. Heat dissipation is thus shown to be influenced by the way heat is generated, whether

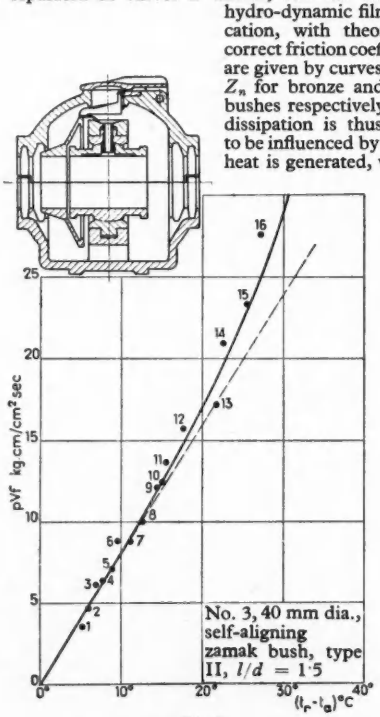

Fig. 3.

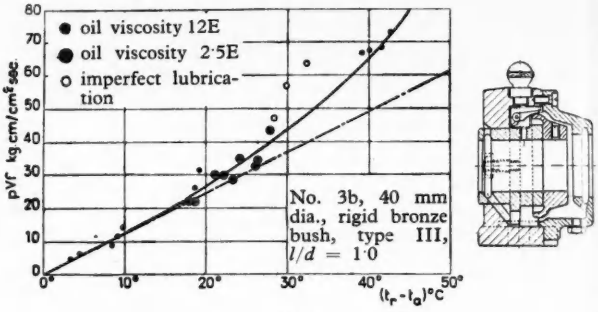
oil viscosity 12E
oil viscosity 2·5E
imperfect lubrication
pVf kg cm/cm² sec
(t_r - t_a)°C
No. 3b, 40 mm dia., rigid bronze bush, type III, l/d = 1·0

Fig. 4.

by perfect film or imperfect lubrication (compare curve B with B_n, and Z with Z_n). Curve Z_n, running constantly above B_n, indicates the higher conductivity of zamak. Moreover, the curves for zamak bushes show a wider stray field for imperfect lubrication, i.e., imperfect lubrication and metallic contact and abrasion is more serious in the case of zamak bushes than for bronze bearings. The tests with self-aligning bearings (Figs. 3, 5 and 6) show hardly any scatter of results. Measured values of f also coincide well with theoretical values whether film lubrication is perfect or not. Imperfect lubrication is therefore much less detrimental if the bearing is self-aligning. Finally, bearings of type I with bronze bushings were run with special low-viscosity lubricating oil so that no perfect film could be formed and large metal contact was maintained. Curve Y, Fig. 8, gives the results. Curves Y and B, taken with imperfect lubrication, show a greater heat dissipation than does the corresponding curve B_n representing tests with perfect film lubrication.

When equilibrium is reached during tests, the amount of heat dissipated and imparted to the ambient air must be proportional to the difference between the temperature t_e at the outside surface of the bearing block and the ambient air temperature t_a. During the tests, the oil bath temperature t_r only was measured and allowance must be made for the difference between t_r and t_e. If e.g. for test points on curve Y or B, the

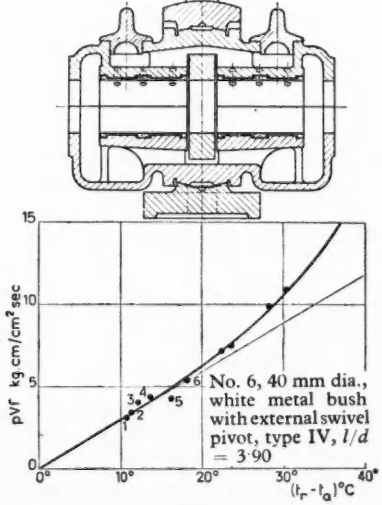

Fig. 5.

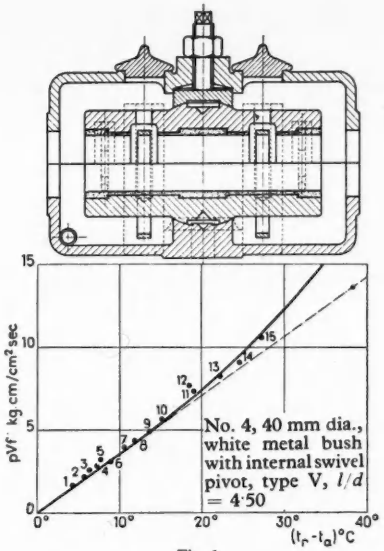

Fig. 6.

differences of the abscissæ, $B - B_n$ or $Y - B_n$, are plotted as functions of the corresponding ordinate differences for the same points, a single curve is found to show, for Y as well as for B, the temperature difference $t_r - t_e$ as a function of the additional amount of heat, pVf_s, generated by metallic friction and conducted by direct metallic contact from the bush to the outside wall of the bearing block (Fig. 9). Similarly, the difference between the abscissæ, for equal ordinates, of curves B_n and Z_n (Fig. 8) indicates that the oil temperature t_r of the zamak bearing is constantly 1·5 to 2·5 deg. C. below that of the bronze bearing, which is evidence of the better conductivity of the zamak bearing even under conditions of perfect film lubrication.

DIMENSIONAL INFLUENCES.

The heat generated at the oil film interface is at first equally distributed to the bearing and shaft surfaces ; it then flows through the bearing, the oil, and the shaft cross-sections to the outside, and is dissipated into the ambient air. However, heat only flows freely to the dissipating shaft surface S'' outside the bearing, if, approximately, the shaft cross-section, through which heat must flow, is equal to the heat generating surface of the shaft, i.e., if $r\,d\alpha\,r/2 = r\,d\alpha\,l/2$ or $n = l/d = 1/2$, where $r\,d\alpha$ is a small segment of the shaft circumference, l the bearing length, and d the shaft diameter. If d is small compared with l, i.e., if n is much larger than 1/2, heat cannot flow so easily through the shaft as it can through bearing and oilbath, and the dissipating shaft surface S'' plays only a minor role as compared with the outside S' of the bearing. The exact quantitative law cannot be established because sufficient experimental data is not available, but results from the author's tests on plain transmission bearings and electromotor bearings equally indicate an equation of the form

$$y = \frac{S''}{S'} = \frac{1}{n^2}\left(\frac{d}{d_0}\right)^2 \quad .. \quad .. \quad (4)$$

For every type of bearing with a length $l = nd$, there is a certain limiting bearing diameter d_0 for which y is unity, and y remains unity even if the bearing diameter is further increased. It is more correct, however, to use the heat protecting length L of the bearing block instead of the bearing length l proper and, for bearings

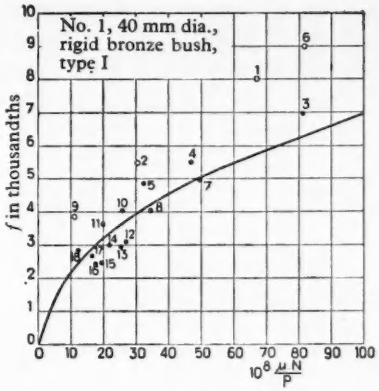

Fig. 7.

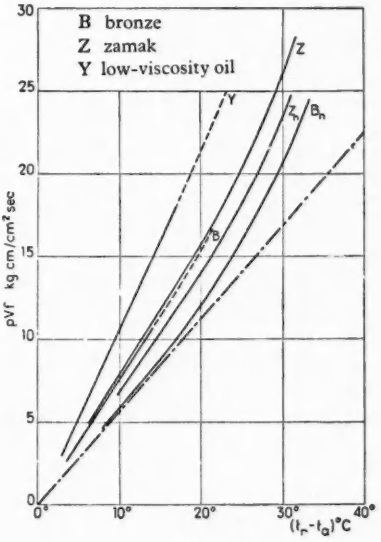

Fig. 8.

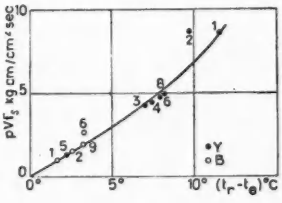

Fig. 9

of types II and III, to allow for the heat conducting influence of the fixed oilring at the bearing side. With these corrections :

$$y = \frac{1}{n_1^2}\left(\frac{d}{d_1}\right)^2 \leqslant 1 \quad .. \quad .. \quad (5)$$

Experiments discussed here conform to this law if d_1 is chosen as 2·7 cm.

The coefficient of convection k_0 of eqn. (3) can now be written :

$$k_0 = \frac{K_\infty}{2} \times \frac{S'+S''}{S'} = \frac{k_\infty}{2}(1+y) =$$

$$= \frac{k_\infty}{2}\left[1 + \frac{1}{{n_1}^2}\left(\frac{d}{d_1}\right)^2\right] \quad .. \quad (6)$$

where k_∞ is the limiting value of k_0 for the case $S' = S''$, or $y = 1$, or $d = d_1$, i.e., for the case when heat is dissipated in equal quantities by the shaft and bearing. This condition is practically obtained by bearing type III, and thus leads to $k_0 = k_\infty = 3{\cdot}60$ as measured. For the hypothetical case $d = 0 = y$, i.e., the shaft takes no part whatever in heat dissipation, and $k_0 = k_\infty/2 = 1{\cdot}8$ m.kg/m²sec. ; a value which corresponds closely to the generally quoted value of the coefficient of natural convection, 15 cal/m² hr.

Eqn. (6) gives the theoretical values which would be obtained if, during experiments, the temperature t_e of the outside wall was equal to the oil temperature t_r. This can be assumed to be practically correct for bearing type III. For the other bearings, a correction factor

$$K = \frac{t_e - t_a}{t_r - t_a} \quad .. \quad .. \quad (7)$$

must be introduced to bring theory and experiment into agreement. In round figures, $K = 1$ for type III, 0·9 for type I, 0·85 for types II and IV, 0·8 for type V.

Similarly, the radiation coefficient should be corrected to

$$k_0' = k_v' \cdot K^4 \quad .. \quad .. \quad (8)$$

with $k_v' = 24{\cdot}1 \times 10^{-6}$ as obtained from tests with bearing type III. No correction is made for heat dissipation by radiation from the shaft because the influence of the shaft speed would introduce additional errors. Calculated values of heat dissipated by radiation can therefore be expected to be slightly higher than the theoretical values. Tests, however, agree fairly well with calculations, and radiation plays a very minor role compared with that of convection.

The final formulæ for practical cases can now be derived :

(a) For a non-ventilated end plummer block (Figs. 3 and 4) :

$$pfV = 1{\cdot}80\frac{S'}{S}K\left[1 + \frac{1}{2}\frac{1}{{n_1}^2}\left(\frac{d}{d_1}\right)^2\right](t_r - t_a) +$$

$$+ 24{\cdot}1 \times 10^{-6}\frac{S'}{S}K^4(t_r - t_a)^4 \quad .. \quad (9)$$

the factor 1/2 signifying that the shaft dissipates heat to one side only.

(b) For an end plummer block ventilated from one side only :

$$pfV = 1{\cdot}80\frac{S'}{S}K\left[\left(1 + \frac{1}{2}\sqrt{v}\right) + \frac{1}{2}\frac{1}{{n_1}^2}\left(\frac{d}{d_1}\right)^2\right]$$

$$(t_r - t_a) + 24{\cdot}1 \times 10^{-6}\frac{S'}{S}K^4(t_r - t_a)^4 \; .. \; (10)$$

(c) For an intermediate plummer block (Figs. 2, 5 and 6), ventilated from both sides :

$$pfV = 1{\cdot}80\frac{S'}{S}K\left[(1 + \sqrt{v}) + \frac{1}{{n_1}^2}\left(\frac{d}{d_1}\right)^2\right]$$

$$(t_r - t_a) + 24{\cdot}1 \times 10^{-6}\frac{S'}{S}K^4(t_r - t_a)^4 \; .. \; (11)$$

where v = ventilation air speed in m/sec., d in cm., and $d_1 = 2{\cdot}7$.

Tests with electromotor bearings made by other workers have, in all cases, established a remarkable coincidence of observed values with limit values calculated from the above formulæ.

CONCLUSIONS.

From test results by Lasche, Falz, an authority on these problems, had established an empirical formula for the heat dissipated :

$$Q = a(t_r - t_a)^{1{\cdot}3} \text{ cal/m}^2\text{, hr.} \quad .. \quad (12)$$

where $a = 2{\cdot}83$ for a transmission bearing in still air without forced oil circulation. According to the tests as described, however, the curves for pfV as a function of $(t_r - t_a)$ are definitely straight lines near the origin, and there is no justification for the coefficient 1·3. Neither is it justified from a physical standpoint since convection currents in the ambient air cannot noticeably influence heat dissipation from a bearing of relatively very small vertical extension. The factor 2·83 (= a) is much too small since Lasche had erroneously determined the " apparent " friction factor f_c from direct friction couple measurements. This could be proved by the author from a repetition of Lasche's experiments. The correct formula, according to the author's tests, should be $Q = 15{\cdot}2(t_r - t_a) \times 2$. This agrees satisfactorily with observed values, and the factor $k_0 = 15{\cdot}2$ for strictly natural convection corresponds to the generally known physical convection coefficient.

A comparison of the Stefan-Boltzmann law with the approximate formula for radiation adopted by the author ;

$$Q_r = 3600\,A\,k_0' \times 10^{-6}(T_r - T_a)^4 = K(T_r^4 - T_a^4),$$

results, when $t_r = 58$ deg. C., $t_a = 28$ deg. C., and $k_0' = 24{\cdot}1$, in a value $K = 4{\cdot}4$ in Stefan-Boltzmann's law. This is only slightly higher than would be expected for a rough cast surface. ($K = 4{\cdot}95$ for a black body). The term $(T_r - T_a)^4$ has been adopted by the author because, with mounting temperature, the heat radiation of the shaft and pedestal is no longer negligible and, therefore, the total radiated heat increases more quickly than the theoretical difference $T_r^4 - T_a^4$ would suggest. Moreover, the chosen approximate term allows for quicker evaluation.

A comparison of different test bearings of 40 mm. diameter under identical conditions of equilibrium (1000 r.p.m., 500 kg. load, 28 deg. C. ambient temperature) shows the following oil temperatures : Type I (Fig. 2) 56 deg. C., type IV (Fig. 5) 56·5 deg. C., type V (Fig. 6) 52 deg. C., type III (Fig. 4) 48 deg. C. Type III thus gives a lower oil temperature, a better safety factor, and an energy absorption reduced to less than 50 per cent. The generally accepted empirical notion that the value of the product pV must be limited, i.e., that with higher speeds V lower pressures p must be chosen, is very misleading. The tests show that *a short self-aligning bearing gives the best results.*

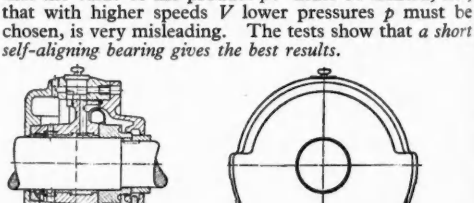

Fig. 10.

The conclusions from these tests led to the development of a bearing as illustrated in Fig. 10. The bearing bush is short, and self-aligning, with abundant lubrication, but without oil splash, from a dished extension of the thrust collar acting as an oil pump. The service temperature under conditions as before is 51 deg. C., i.e., not higher than for a similar ball bearing, the type factor is $K = 0{\cdot}9$. The shape is simple and the bearing block can be equipped equally well with plain bushes as with ball races.

CLASSIFIED ABSTRACTS

Numerous important abstracts which, for lack of space, cannot be published in our main editorial columns, are regularly included in condensed form in this section. Subscribers may obtain photostat copies of all original articles at cost.

ELECTRONICS

A New D.C. Voltage Stabilizer.

By V. KUSSE. (From *Elektrotechnik, Germany*, Vol. 1, No. 3, September, 1947, pp. 95-96, 2 illustrations.)

A NEW d.c. voltage stabilizer, permitting a high degree of stabilization in spite of considerable variations in the supply voltage and in the load conditions, has been developed by Peter Steinlein, A.G., Zöblitz, Russian Zone, Germany. The stabilizer consists of a comparator and a regulator circuit. When the supply voltage U_1 increases, the current through resistor R_1 increases and there is also a partial current rise through valve $V2$ so that point A (see Fig. 1) is raised to a higher

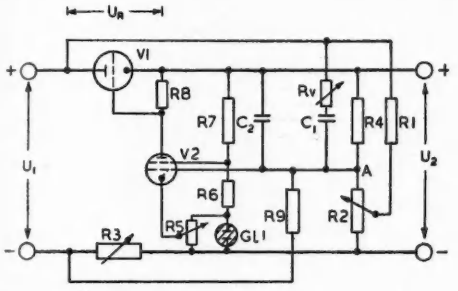

Fig. 1. **Circuit diagram of d.c. voltage stabilizer.**

potential. The cathode of valve $V2$ is held at a constant potential determined by the drop across the glow-type regulator valve $Gl\,1$, therefore the grid bias of valve $V2$ will increase, so that there will be a rise in the current through valve $V2$ and in the voltage across R_8. The internal resistance of $V1$ then increases, and the potential drop across this valve becomes so large that the output voltage remains constant. When voltage U_1 decreases, the same phenomena take place in the reverse direction, and U_2 again remains constant. This so-called "forward" regulation compensates for any fluctuations coming from the network. To eliminate fluctuations due to load variations, an additional "backward" regulation is provided. When U_2 varies, the potential of A also varies as a result of the phenomena already described, owing to variation of current in the potential divider R_2, R_9, and regulation occurs then in the same way as for forward regulation. Adjustment of R_3 enables the supply voltage to be stabilized to the required value. The condensers C_1 and C_2 serve to eliminate the hum voltage. The internal resistance of valve $V1$ and the current through valve $V2$ are sensitive to filament voltage variations, and the best way to obtain a high degree of stabilization would be to use a magnetic control device for the filament voltage, which enables a constant output voltage U_2 to be obtained over long periods of time. The input voltage $U_1 = U_R + U_{a1}$ where $U_R = U_a =$ = anode voltage of $V1$, while I_a = load current. Regulation is limited by the maximum cathode current, the maximum anode power loss, the cold anode voltage, and the grid voltage curve $U_a = 0$ volt. The regulating range decreases with increased loads.

FOOD PRODUCTS

Hydrogen Peroxide and Its Use for the Sterilization of Milk.

By M. A. DAHLEN. (From a Report published by the *U.S. Department of Commerce*, P.B.-31003, 66 pages.)

IN the Milan area in Italy all milk is sterilized by the use of hydrogen peroxide rather than by pasteurization. Use is made of a special type of electrolytic, 39 per cent concentration of hydrogen peroxide, of very high purity and stability which yields 130 times as much active oxygen by volume. It is claimed that the addition of 0·1 per cent of this peroxide, by weight, results in sterilization in about 8 hours which lasts for at least three days. The antiseptic effect of the hydrogen peroxide continues to some degree through long storage periods.

High purity hydrogen peroxide is manufactured by producing a very pure potassium persulphate electrolytically, which is then decomposed to hydrogen peroxide and purified by destillation under vacuum.

Another development not yet commercially used, is the production of a solid compound consisting of 35 per cent hydrogen peroxide and 65 per cent urea compound for use in tablet form, each tablet for sterilizing 25 kg. of milk. These tablets are more effective than liquid hydrogen peroxide.

The report gives technical details and describes bacteriological tests, the manufacture of the hydrogen peroxide, etc.

HEAT, PRESSURE AND COMBUSTION INSTRUMENTS

Flow Calorimeter for Specific Heats of Gases.

(From *Technical News Bulletin, National Bureau of Standards, U.S.A.*, Vol. 31, No. 10, October, 1947, pp. 112-113, 1 illustration.)

A NEW flow calorimeter for more accurate measurements of the specific heats of gases has been developed by R. B. Scott of the Bureau's cryogenics laboratory. The greater precision of this instrument is chiefly due to the almost complete elimination of heat leaks. The small heat capacity of the calorimeter also results in improved accuracy through the easier and more rapid attainment of a constant temperature distribution within the system.

The heat capacity per unit volume of a gas is so low that small accidental heat leaks are often comparable in size to the heat used in actually raising the temperature of the gas. Reduction of the ratio of heat loss or gain to heat input is thus one of the chief problems of gas calorimetry. In the calorimeter constructed at the Bureau, this is accomplished by causing the gas to flow continuously at a uniform rate through an insulated chamber in which it is heated electrically. The heat capacity is then calculated from the heat input, the temperature rise of the gas, and the rate of flow. With gas calorimeters of this general type, a correction is usually made for heat leaks by making measurements at varying flow rates and extrapolating the apparent specific heats to infinite rate of flow, where such errors are negligible. In the new apparatus, however, special precautions have reduced heat leaks to such an extent that a correction for them is unnecessary.

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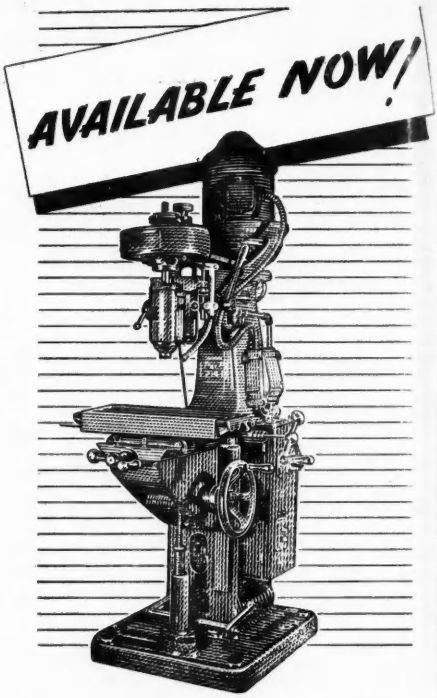

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The entire calorimeter is immersed in a constant-temperature bath. The gas whose specific heat is to be measured enters the system through a copper helix, in which it is brought to the temperature of the bath. It then flows into the calorimeter proper, where it traverses a labyrinth surrounding a constantan heater, and leaves the calorimeter through a throttle valve. The temperature rise within the calorimeter is determined by appropriately located thermocouple junctions.

A uniform rate of gas flow is obtained by maintaining a constant pressure on the inlet side of the calorimeter and a constant lower pressure at the outlet. Adjustment of the throttle valve in the outlet tube then provides the desired rate of flow, which is determined by weighing the gas collected within a given time.

Heat leaks to or from the interior of the calorimeter are minimized in several ways. Conduction along the inlet and outlet tubes is reduced through the use of tubing of monel, having a wall thickness of 0·01 inch. Radiation along the tubes is prevented by a series of baffles, which in addition promote thermal equilibrium between the gas and the tube walls. Heat leaks due to either conduction or radiation are also lessened by providing a long section of tubing between the inlet and the heater, and by heating the outlet to the final temperature of the gas. Radiation to or from the inner portion of the calorimeter is prevented by a copper radiation shield kept at the temperature of the inner adjacent calorimeter wall by means of an electric heater.

The new calorimeter has been used to determine the specific heats from — 30 deg. to 90 deg. C. of isobutane, isobutylene, 1-butene, *cis*-2-butene, butadiene, styrene, and ethylbenzene.

HEAT TREATMENT

One Salt Bath for both Carburizing and Cyaniding.

By F. STEIGERWALD. (From *Materials and Methods, U.S.A.*, Vol. 26, No. 1, July, 1947, pp. 75-77, 2 illustrations.)

THE combination of hard, wear-resisting case and relatively soft, tough core makes the resulting material more valuable for many applications than either the high or low carbon steel would be. This desirable result can be achieved *inter alia* by salt bath treatment, but the usual practice has presented numerous difficulties. Early baths of this type have used sodium cyanide as the active carburizing agents, and this can still be considered as the most useful of the molten salts for carbon enrichment of steel. Unfortunately the case thus obtained is not a true carburized one. The result seems to be a mixture of carbon enrichment and nitriding of the surface. In addition the composition of the bath changes as the bath is used and the rate of change is not accurately predictable.

A recent development in cyanide baths seems to overcome most of these disadvantages and, at the same time, to improve the quality of the work. The distinctive features of the new salt bath are gas activation of the bath and complete water solubility of the salt adhering to the work. Therefore cleaning difficulties are eliminated. The salt bath is of the cyanide type, but the case produced is a true carburised case. Activation of the bath with oxygen gas is responsible for the difference from the old types of salt baths. The same bath can be used for both carburizing and cyaniding, serving the former purpose one day when operating with the gas activating agent and the latter the following day without the gas. It melts at 1,150 deg. F. and works well within the range of 1,300 to 1,750 deg. F.

Oxygen gas is bubbled slowly through the molten salt feeding in just enough to permit a slight evolution. A needle valve and rotameter help to gauge the quantity of gas required. The oxygen is carried below the surface of the salt in a tube about $^1/_4$ in. in diameter and without any provision for stirring. If the flow of gas should be accidentally cut off after the bath is in operation, no harm will result as the bath remains effective for 3 to 4 hours after activation.

Cyanide content of the molten salt must be maintained at above 15 per cent and a daily replenishment schedule is advisable, addition of about 5 to 10 per cent of the weight of the bath is suggested. This amount will also maintain the carbon cover over the bath while in service.

Pots for the bath can be of any of the materials now widely used for salt baths. When operated at 1,700 deg. F. a case of about 0·015 in. is produced during the first hour of operation ; two hours will produce a thickness of about 0·025 in. and each succeeding hour will increase the depth of case by about 0·005 in.

PERSONNEL

The Psychophysiological Selection of Airmen.

By P. CHAUCHARD. (From *La Revue Scientifique, France*, Vol. 9, No. 3261, November 15, 1946, pp. 565-67, 3 illustrations.)

It is a fairly recent development to investigate the psychological problems of aircrews and, as a consequence of it, psychophysiological examinations were added to the medical ability tests of airmen. A " good pilot " is distinguished by special characteristics of temperament, mental reactions, alertness, decisiveness and intelligence. The good results which psychophysiological examiners obtained have led to remarkable progress and refinement of tests applied during the last war, and experts are continuing to perfect the methods still further.

The correct assessment and selection of pilots-to-be is obviously a function of great practical value. Those who have to be rejected during training necessitate a loss of instructors' time, a waste of material, and the occupation of places which should be held by candidates of greater aptitude. Malméjac has stated that, if there is no selection, 10,000 candidates must be trained to obtain 4,440 good pilots.

Supposing one million French Francs is the cost of training a candidate, then each pilot costs 2,252,000 francs, and the 4,440 pilots cost 10 milliard francs. On the other hand, if selection is made under optimum conditions 6,740 trainees provide 3,769 certified pilots and the net cost of a pilot is only 1,788,212 francs. The 4,440 men work out at 7,939,927,680 francs which means a saving of more than 2 milliard francs. Among rejected candidates there are some exceptions who would make good pilots just as there are some among those selected who do not make good pilots, but such exceptional cases are inevitable in facing a problem of such magnitude. Psychophysiological selection is gaining ground in many fields, especially in the Armed Forces.

The psychophysiologist's task is divisible into three stages :

(1) To analyse the qualities required in a good airman. This requires close contact between examiners and instructors.
(2) To work out the tests which best reveal these qualities.
(3) To check the value of the tests by comparing their results with those of training and practice. This leads to alterations of test methods and to reconsideration of the relative values of the tests.

The degrees of competence and ability are decided by marks from 1 to 9. Then the proportion of those eliminated in each mark group is calculated. For example " good judgment," or the ability to make the

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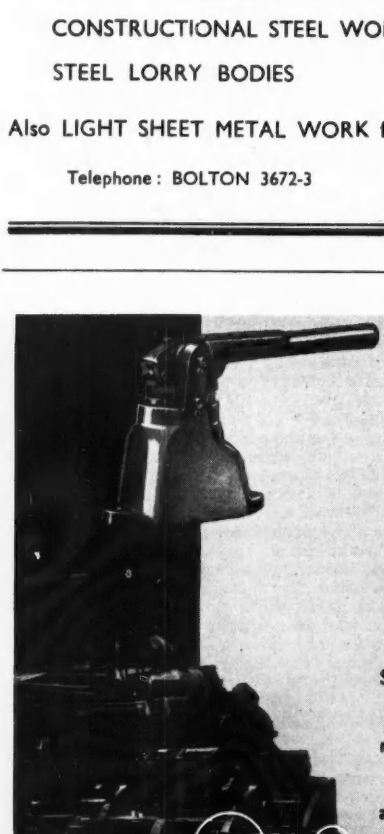

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best choice when confronted with a practical problem, has given 27 per cent rejections for the marking of 9 and 78 per cent for a marking of 1. From the combination of these results Malméjac draws the following estimation of a good pilot : judgment, memory, intellectual capacity, imagination, rapid and exact observation, discernment of localities, steady and dispersed attention, initiative to move, skill and self-control. What matters is the general psychological make-up arrived at by grouping all particular qualities and expressed by the mark resulting from the tests.

Here is an example of the testing of distracted attention (Piéron) :—The candidate sits at a table, holding in his right hand a handle which he can move backwards and forwards by pressing a button with his thumb, whilst his left hand presses the lever of a gravity meter which has to be kept in equilibrium and his feet rest on two pedals. In front of him a mirror arrangement, like a periscope, shows him a film displayed on a screen some distance away, a white-red-white signal, a milliamperemeter, and a power meter, the needle of which rotates continually. He is instructed as follows :—Press down the pedal under the right foot when the white signal lamp on the right lights up and the pedal under the left foot when the white lamp to the left lights up ; incline handle forward when the needle of the milliamperemeter deviates to the right and pull it backward when it deviates to the left ; press the knob of the handle when the needle is arrested in order to set it going again ; finally, push the handle vigorously forward when a siren sounds. The red light warns the candidate that he ceases to keep the gravity meter balanced. Errors, as well as times of reaction are registered automatically. Also, the candidate must observe the film, so as to be able to answer relevant questions.

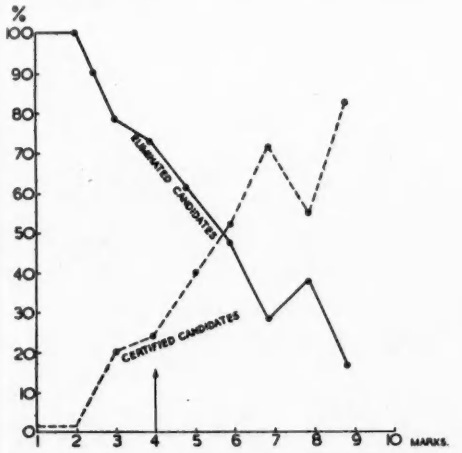


Fig. 1. **Percentage of certified and eliminated candidates according to their mark (importance of mark 4).**
The irregularity of marks 7 and 8 derives from the inadequacy of the test which was later improved.

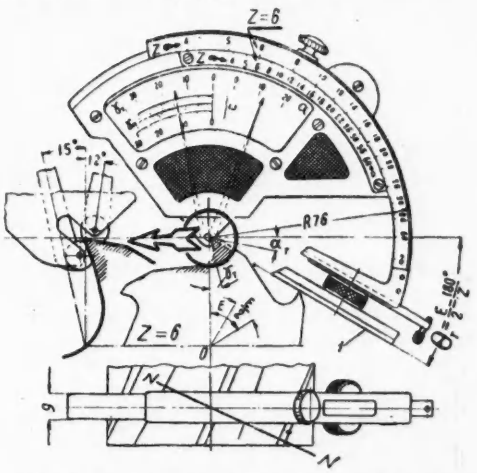
Once the marks are ascertained by examination, the question arises how to proceed with the necessary eliminations. One way is to accept as many candidates with the highest marks as there are places to be filled ; the alternative solution is to fix a certain mark as the elimination mark. Malméjac prefers the latter method and concludes from the diagram (Fig. 1) that mark 4 should be this lower limit, because from this mark the percentage of eliminations falls rapidly and continually, and the percentage of certified airmen rises accordingly. The group of candidates with marks above 4 is expected to achieve the optimum of success, i.e., to produce the greatest number of airmen from the minimum of trainees without risking an excessive number of eliminations and, therefore, at a minimum of cost.

SCIENTIFIC INSTRUMENTS AND PRECISION TOOLS

Gauge for Measuring Milling Cutter Angles.

By B. A. KURENKOV. (From *Stanki i Instrument, Russia*, No. 7, 1947, p. 18, 1 illustration.)

CORRECT cutting angles can contribute very greatly to the cutting efficiency and long life of milling cutters and other cutting tools, but the checking of these angles during grinding has hitherto been so awkward as to present a serious handicap to the maintenance of high standards. This difficulty has been overcome by Neprin who designed a simple angle-measuring gauge shown on the accompanying illustration.



The Neprin gauge consists of a main body and two pointers, the bottom ends of which bear on the cutting angles of the tooth undergoing inspection whilst the top ends move over a scale graduated in degrees. In order to locate this main body in the correct position for measuring, it carries a sliding attachment which must be set in accordance with the number of teeth of the cutter. The correct reading is obtained when the short ends of the pointers embrace the cutting edge of one tooth, the straight edge (1) of the sliding attachment, correctly set, rests on the tooth next to it and the instrument is held perpendicular to the axis of the cutter.

TRACTORS

Tractor " Stalinetz-80."

By YU. I. CHEREMOVSKY. (From *Vestnik Machinestroenia, Russia*, No. 2, 1947, pp. 22-23, 1 illustration.)

THE new Russian heavy caterpillar tractor " Stalinetz-80 " is similar to the old S-65, but is more powerful and incorporates certain improvements which are expected to double its useful life. The main characteristics are as follows :—

The engine is a 4-cycle Diesel with precombustion chambers and has 4 cylinders 145 mm. dia. × 205 mm. stroke, a compression ratio of 15·5, fuel consumption of 0·45 lb./h.p./hour and a maximum rating of 93 h.p. at 1,000 r.p.m.

The complete tractor weighs 11 tons and its overall dimensions are 13′ 6″ × 8′ 2″ × 6′ 8″. Track gauge

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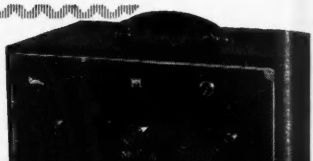

The chief features of this compact oscillator are its wide frequency range, constant output and low harmonic distortion. Arrangements have also been made whereby the amplifier may be operated separately.

It is extremely useful for studying the audio frequency characteristics of transformers, amplifiers, transmission networks and allied radio and telecommunication equipment.

There are many other uses for this versatile instrument which should form part of the test equipment in all electrical development and research laboratories.

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is 6′ 2″, clearance 15 1/2″, height of drawbar 18″, and the track pressure on the ground is 7 lb./sq. in. There are 5 speeds forward and 4 in reverse, ranging from 1·4 miles per hour with a traction effort of 2 1/2 tons to 6 m.p.h. with 2 tons. The fuel tank takes 42 gallons and the lubricating system capacity is 4 1/2 gallons.

Pistons have 3 pressure piston rings and one scraper ring only, and the crankshaft has only four balance weights. Cylinder liners are of chrome-nickel cast iron and these as well as the crankshaft are hardened by the high-frequency induction process.

Both inlet and outlet valves have been reduced in diameter compared with previous designs and are made of chrome-nickel steel and silchrome steel respectively. The time of opening has been lengthened.

Lubrication is by means of a gear pump having three working sections for different duties, one of which is to pump oil from the back of the crank case to the centre to ensure good lubrication at all inclinations. The oil is cooled in an auxiliary radiator and passed through an improved type of filter, so that the "life" of the oil is 240 hours as compared with 60 hours in the S-65 model.

To facilitate starting, the inlet pipe is equipped with a burner supplied with fuel from a hand pump and ignited electrically. This preheats the air and the walls of the inlet passages.

The final drive to the sprockets is effected through conical gears with spiral teeth and the driving sides of the friction clutches are splined onto the half-shafts. The friction surfaces are of a new metallo-plastic compound throughout. The effort required for clutching in the final drive is reduced to 2 1/4 lb. by means of a servo system.

The tractor has a rigid electro-welded chassis based on two principal longitudinal members of box section.

WELDING

Properties and Weldability of Ni-Cr-Mo Special Steels.

By E. HENRION. (From *Revue de la Soudure, Belgium*, Vol. 2, No. 2, 1946, pp. 65-71, No. 3, 1946, pp. 111-118, No. 4, 1946, pp. 166-169, and Vol. 3, No. 1, 1947, pp. 14-20, 17 illustrations.)

THE chemical resistance of highly alloyed special steels is primarily based on "autoprotection." Corrosion externally produces a compound which forms a continuous layer over the entire surface and protects the metal beneath it from the corrosive agent. With 13 per cent of Cr a Cr-Ni steel possesses the resistance necessary against oxidizing agents and nitric acid owing to the oxidization of Cr, which is more rapidly attacked than Fe, whilst a certain content of Ni, which resists bases and stronger acids, safeguards the homogeneity of the metal. Besides Cr and Ni, there are a number of other useful elements, such as Mn, Si, Mo, W, Ti, Ta, Cb, Nb, and Va. The unavoidable C generally has a noxious effect, otherwise needed to render certain steels very hard or machinable, and its presence definitely reduces the weldability of the steel if its percentage exceeds certain very low limits. Si increases resistance to oxidization at high temperatures, but with more than 2 per cent of Si the steel becomes too hard. Mn has qualities similar to Ni and Mn-alloyed special steels are classified according to the percentage of the Mn contents. Mo has a remarkable effect on the chemical properties. It particularly increases the resistance to strong chlorides at high temperatures and improves mechanical properties. Moreover, it plays an important part in welding. W adds to the mechanical strength at high temperatures and "stabilises" the C, but other elements surpass it in efficacy. Ti prevents the intergranular corrosion but, owing to its great affinity to O and N, it almost vanishes from the deposited weld and even the neighbouring zone of the basic metal shows a loss of Ti content. In this respect Cb and Nb are superior to Ti, as their losses due to oxidization and nitration during welding never exceed 30 per cent. Va, which has an effect similar to that of Ti, is rarely used in modern practice.

The essential role of the stabilisers Ti, Cb and Nb in a Cr-Ni steel consists in favouring the formation of carbonates at their expense during thermal treatment, especially in welding. Thus, they assist the effects of Cr, the presence of which is necessary for the preservation of homogeneity and for the prevention of intergranular corrosion.

If attention is paid to chemical composition and every case is carefully considered, highly alloyed stainless steels are readily weldable. All welding methods are possible, except the carbon arc process, with its attendant carbonization, oxidization, and nitration. Because it is preferable to avoid overheating, inverse polarity is used when arc welding and small torches are used for oxy-acetylene welding. The electrodes used are coated Cr-Ni rods with a certain addition of Mo and a low C content. As their resistivity is 12 times greater than that of mild steel, the electrodes are shorter and the current is only 25 per cent of its usual value. High resistivity also facilitates spot welding and resistance welding. High currents, short welding times, and increased pressures of the electrodes characterise the conditions required for the spot welding of alloyed steels.

Steels with Cr-Ni percentages of 18/15, 25/12, 25/20, and 25/25, do not suffer from the disadvantages due to carbonization. They are perfectly weldable and possess excellent mechanical properties with high heat resistance.

The stainless steels used for tools and cutlery are Cr steels with appropriate Mn additions. Weldability depends on their C content.

The ferritic non-hardenable steels have a Cr content of 18-20, 22-25 and 28-30 per cent, but there is also a variety with 3 per cent Ni, which is martensitic. These steels resist oxidization and sulphuric attacks, and the Ni variety also resists salty air. Normally, they do not weld well, owing to coarseness of the grain in the transition zone, and welding should be restricted to those cases where the best mechanical strength is not required.

Ni-Cr-Mo steels (Ni $>$ 3 per cent Cr $>$ 1 per cent, Mo $>$ 0·2, C $>$ 0·30, Si 0·15, Mn 0·50 per cent) are used in cases where resistance to great impacts is necessary. These steels offer the advantage of good weldability (by thermite, arc, or oxy-acetylene welding) and are important for railway trackwork.

Manganese steels with 10 to 24 per cent Mn and 0·6 to 1·4 per cent C can withstand impact and heavy usage (crushers, pinions, scraper blades, excavator buckets, etc.). They tend to develop extreme surface hardness and, therefore, brittleness whilst, with resilience thus reduced, welding becomes more difficult. Conditions improve with an additional Ni content of 3 per cent, and such Mn-Ni steels are effectively weldable, both by arc and oxy-acetylene welding.

Special reference should be made to the use and weldability of compound sheets consisting of 2 or more sheets of different steel compositions. They are increasingly used in the chemical industry. These compound sheets are manufactured by laminating a thin sheet of stainless steel with a thick sheet of ordinary mild steel. The latter provides the mechanical strength, whereas the thin sheet of alloyed steel withstands chemical corrosion. Welding can be advantageously used for the manufacture of these laminated sheets, but with all the precautions due to the properties of the alloyed sheet.

Industrial Electrification. By J. W. McQUILLEN. *Publisher*: Sir Isaac Pitman & Sons, Ltd., London. 116 pp., 25 figures. Price: 12s. 6d.

This is an extremely useful book for electrical engineers into whose care is entrusted the design, installation, and maintenance of the electrical network, substations and electrical equipment of factories and other industrial buildings. A chapter is devoted to flame-proof installations for hazardous areas.

Power Station Efficiency. By C. W. PRIEST. *Publisher*: Sir Isaac Pitman & Sons, Ltd., London. 119 pp. 26 figures and tables. Price: 10s. 6d.

The need for economy in the use of coal has become of paramount importance for British industry, especially since this commodity became scarce and increasingly expensive. The book of Mr. Priest, who is passing on twenty years' experience in generation, is to aid the practical operator in ensuring the greatest possible efficiency from power-station operation. It is a thoroughly practical book.

Aircraft Engines. By A. W. JUDGE. *Publisher*: Chapman and Hall, Ltd., London. 513 pp., 390 figures. Price: 36s.

A rather comprehensive and mainly descriptive book on aircraft engines. The present, second edition gives an account of the later types of piston engines. A new chapter in the book deals with recent developments and future trends.

Mathematical Theory of Rocket Flight. By J. BARKLEY ROSSER, ROBERT R. NEWTON and GEORGE L. GROSS. *Publisher*: McGraw-Hill Book Co., Inc., New York and London. 276 pp. Price: 22s. 6d.

This is the final official report of the Allegany Ballistics Laboratory to the Office of Scientific Research and Development concerning the work done on the exterior ballistics of fin-stabilised rocket projectiles, with the addition of a considerable amount of expository material. The book is intended not only for trained scientists but also for persons with little scientific training who are interested in what makes a rocket go.

Pressure Vessels for Industry. By H. M. SPRING, JR. *Publisher*: McGraw-Hill Publishing Co., Ltd., London. 259 pp. 241 figures. Price: 17s. 6d.

This book deals with various types of pressure vessels, but it is in no way comprehensive. After much too brief chapters on compressed-air systems and on pressure vessels for steam and hot-water services, chapters on the construction, design, inspection and safety practices in some industries such as in pulp and paper mills, rubber industry, textile industry, etc., are included. The reproduction of the large number of photographs (many of them very interesting) is much below the standard usually adhered to by the McGraw-Hill Company.

Textbook of Illuminating Engineering. By J. W. T. WALSH. *Publisher*: Sir Isaac Pitman & Sons, Ltd., London. 191 pp., 135 figures. Price: 17s. 6d.

Written at the request of the Illuminating Engineering Society by Dr. Walsh, their former President, a recognised authority on the subject, this book, written in a clear and concise style, will be of much assistance to students preparing for examination in Illuminating Engineering (Intermediate Grade) of the City and Guilds of London Institute. The book will also be a valuable addition to the library of engineers and others interested in the fascinating subject of illuminating engineering.

The Maintenance Electrician's Handbook. By D. J. HARTSHORNE. *Publisher*: Sir Isaac Pitman & Sons, Ltd., London. 136 pp., 85 figures. Price: 8s. 6d.

A useful little book for people concerned with the overhauling and maintenance of electrical installations.

Newnes Plastics Manual. By F. J. CAMM, H. W. GILBERT-ROLFE and D. C. NICHOLAS. *Publisher*: George Newnes, Ltd., London. 242 pp. 115 illustrations. Price: 17s. 6d.

TUBULAR AIRHEATERS OF WELDED CONSTRUCTION.

A. N. Clark, J. Loughray and W. D. Garrick, leading members of the technical staff of Messrs. Yarrow & Co., Ltd., Scotstoun, Glasgow, have been awarded a prize of two thousand dollars by the James F. Lincoln Arc Welding Foundation in America for their paper on Tubular Airheaters of Welded Construction.

The Lloyds Register of Shipping has placed Messrs. Yarrow & Co., Ltd., on the list of firms recognised by the Committee for the manufacture of Class I. Welded Pressure Vessels (Fusion Welding).

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The address of Messrs. Howard Clayton-Wright Ltd., manufacturers of gaskets, packings, flexible bearings, engine governors, etc., is now Wellesbourne House, Wellesbourne, Warwickshire. Telephone Nos. 316-7-8.

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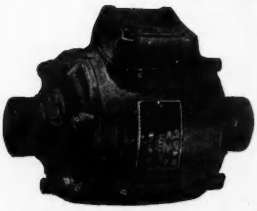

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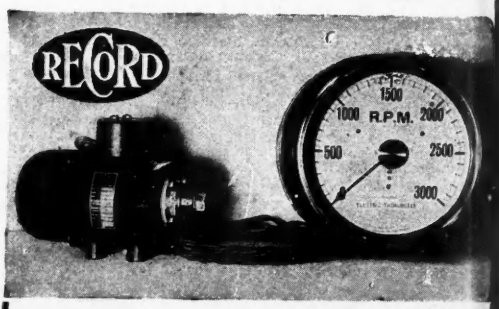

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